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Examining the Vulnerability of Communities and Residents in the Houston Metropolitan Statistical Area with Special Attention to Hurricane Harvey

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Examining the Vulnerability of Communities and Residents in the Houston Metropolitan Statistical Area with Special Attention to Hurricane Harvey

by

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Report

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Dedication

I dedicate this report to the victims of Hurricane Harvey and the countless individuals and families still recovering from the disaster.

Acknowledgements

I would like to thank professors Junfeng Jiao, Katherine Lieberknecht, and William Spelman for working with me on this research and offering continual encouragement and thoughtful recommendations as I prepared for this report. I am also grateful for the help of New York Times reporter Robert Gebeloff, without whose assistance, I might not have found the FEMA data sharing site for Hurricane Harvey damage assessment data. I also extend my thanks to the countless researchers, city, county, state, and federal employees, and non-governmental agency stakeholders for taking the time to answer my questions and trying to help me find the data I needed.

Abstract

Examining the Vulnerability of Communities and Residents in the Houston Metropolitan Statistical Area with Special Attention to Hurricane Harvey

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The University of Texas at Austin, 2018

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In addition to the hazards posed by the physical landscape, social factors and systems affect the vulnerability of communities and their residents to natural disasters. Such demographic and socio-economic factors influence the ability of individuals and families to anticipate, prepare, and recover from disasters. The region around Houston, TX and its increasing propensity to flood acts as a case study. This report describes the various measures of social vulnerability and illustrates their spatial pattern in the Greater Houston region, and compares it with the distribution of damages from the recent disaster of 2017, Hurricane Harvey. While findings supported a concentration of social vulnerability in the inner city, these households seemed to be negatively correlated with damage calculations. However, these results are not conclusive as this report was forced to use limited datasets; better and more complete information would improve the analysis. This report emphasizes the importance of spatial analyses of social vulnerability in emergency management, disaster

response, and resilience planning efforts to support the recovery and improvement of the Houston region in the years after Harvey.

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Chapter 1: Introduction

In the wake of Hurricane Harvey, a devastated Houston is starting to recover and rebuild. Harvey was a storm unlike anything the Houston region had seen before, despite being hit by two 500-year floods in the previous two years. As sprawling development and climate change continues to intensify in the region, these flooding events will presumably keep occurring in Houston. In addition to sprawl, other development patterns, such as concentrated poverty and segregation can cause critical impact when disasters strike, exposing vulnerable populations to greater risk. Thus, social factors and systems intermingle with the physical geography to make certain communities more vulnerable to hazards.

This report focuses on the demographic and socio-economic factors that shape vulnerability and compiles research to show that disaster events compound existing conditions of poverty and inequality as the most underprivileged populations are more at-risk to natural hazards, less likely to have access to adequate information and necessary resources to prepare and respond to anticipated threats, and less able to recover or bounce back after having been impacted by disasters. Using variables laid out by the review of the literature and the Houston region as a case study, this report aims to illustrate Houston's history of flooding, the conditions leading up to Harvey, and where the most vulnerable populations are living in the Greater Houston area. Additionally, this report addresses whether there is a spatial pattern to the location of vulnerable populations. By compiling a social vulnerability index composed of Census block group data from the American Community Survey (ACS) estimates using ArcGIS software, this report spatially maps the relative concentration of social vulnerability across the nine-county Houston Metropolitan Statistical Area (MSA). In doing so, this report points out the uneven nature of disaster recovery and targets areas for planners, emergency managers, and other local officials on which to focus.

Additionally, this report also looks at the impact left by Hurricane Harvey and the available data on assessed damages. By spatially locating the damages in ArcGIS in Census block group across the Houston region, the damage assessment data can be compared to the social vulnerability data. Using STATA statistical modeling, this report analyzes the correlation between social vulnerability and assessed damages. While the results are not as expected, this report points out the limitations of the various damage assessment data available and suggests that the U.S. Federal Emergency Management Agency (FEMA) and other federal agencies should make more complete data more accessible to facilitate the monitoring and progress tracking of disaster recovery efforts. This report concludes that spatial analyses of social vulnerability should be an important factor in emergency management, disaster recovery, and resilience planning efforts to help communities prepare, respond, build back and reestablish themselves, and thus reinforce community resilience though just and equitable plans, policies, and actions.

Chapter 2: Social Vulnerability Assessments to Hazards

Floods and their alteration of natural and human environments has historically been the focus of hazard research since the field's inception (Cutter et al. 2000). Traditional research explained flooding as a function of precipitation, soil typology, landscape slopes and features, and other biophysical characteristics. However, researchers soon recognized that natural hazards, such as floods, are not just physical events, but also involve human society and the built environment.

During the middle of the 20th century, research was focused on analyzing why people resided in hazard zones and how society could be readjusted to reduce the impact. Such problem-solving investigation using hazards assessments to identify risk areas was integral in influencing national flood management policy and formed the basis for hazard mitigation planning (Cutter et al. 2000; Cutter et al. 2008). For decades, hazards research was centered around extreme natural events, and *vulnerability* was broadly thought of as exposure to hazards, such as floods, storm surges, and winds, and associated potential impacts and losses. But, in the 1970s researchers refocused attention on what Susan Cutter and her colleagues (2009) call "the human drivers of vulnerability," or the social, cultural, economic, and political factors and systems that increased hazard risk and susceptibility to harm (Cutter et al. 2009; Cutter et al. 2000; Peacock et al. 2011). Thus, *social vulnerability* to natural hazards has become an important concentration of hazards assessments.

SOCIAL VULNERABILITY

Today, there is broad consensus among researchers that natural disasters are not simply physical events, but the product of the interaction between social and natural systems. Subsequently, the social fabric and socioeconomic geography of communities is an important indicator of vulnerability, in that a community's demographic characteristics, resource access, and knowledge about risks and hazards impact their overall capacity to adequately prepare for and respond to disasters. In this way, disasters are not "equal opportunity" events and do not affect all groups the same way even if they all experienced the same level of flooding or storm inundation (Van Zandt et al. 2012). For instance, while wealthy, highly educated, and privileged communities have the knowledge and resources to anticipate hazard threats and bounce back from disaster events, other groups suffering from poverty and discrimination do not, and consequently are less likely or able to recover or survive natural disasters.

While physical vulnerability denotes the potential for losses due to the exposure to hazards and the characteristics of the environment, social vulnerability focuses on the characteristics of certain persons and groups that affect their capacity to prepare for, respond to, and recover from hazards (Peacock et al. 2011; Cutter et al. 2000; Blaikie et al. 1994). Social vulnerability explains how some social groups are more susceptible to loss and critical impact by hazard events due to factors like lack of access to resources, including information and knowledge, lack of political power and representation, social dependence and special needs, lack of adequate infrastructure and transportation, and lower quality buildings (Cutter et al. 2000). Thus, social vulnerability is a "pre-existing condition" that describes different groups and is place-sensitive (Cutter et al. 2009). Walter Peacock and colleagues (2011: 10) explain these effects:

> "Importantly, socially vulnerable populations are not evenly distributed throughout communities. Instead, they tend to be clustered into particular locations or neighborhoods. On one hand, such clustering exacerbates the impact of disasters; on the other hand, it may also make it possible for public officials to address such disparate outcomes through spatially-targeted efforts both prior to and after a disaster."

People and households are not randomly distributed in space. They are concentrated in fairly predictable spatial patterns based on household characteristics, and these patterns increase exposure to flooding and other hazards, which exacerbates inequality and jeopardizes the vitality of the whole community. As such, spatial planning stands as the first step in reducing social vulnerability and thereby increase the overall resiliency of a community.

Indicators of Social Vulnerability

The literature on social vulnerability has identified many factors that increase or decrease the impact of natural hazards on local populations. The dimensions of social vulnerability cited most often are related to race/ethnicity, socioeconomic status (income and poverty), age, gender, and special needs populations (Cutter et al. 2009; Van Zandt et al. 2012; Flanagan et al. 2011; Berke et al. 2015; Tierney et al. 2001; Heinz Center 2002; National Research Council 2006). Other factors include language, education, employment, transportation, and housing tenure and type. Many of these indicators can be expressed in a single value or quantitative calculation to represent a characteristic of a population and how it contributes to vulnerability (Table 1). Additionally, these factors often present in combination and compound one another to exacerbate vulnerability (Van Zandt et al. 2012; Morrow 1999).

An individual's economic standing is the most prominent indicator of their ability to prepare for a potential hazard or recover after a disaster (Van Zandt et al. 2012; Flanagan et al. 2011; Cutter et al. 2000; Morrow 1999). For example, those with more income have more resources available to purchase supplies and install home protections to prepare for a disaster and can absorb losses and rebuild with more ease than lower-income households (Cutter et al. 2000; Van Zandt et al. 2012). Although the monetary values of the property losses of the wealthy may be greater, the losses for the poor have a greater impact comparatively. Flanagan et al. (2011: 4) write that for these lower-income households, "lost property is proportionately more expensive to replace, especially without homeowner's or renter's insurance." Furthermore, poorer households are less likely to have access to adequate transportation to facilitate evacuation during a disaster and are more likely to reside in lower-quality housing due to "trickle down" housing processes whereby the poor and minorities are cycled into older housing that is weaker and less reliable in times of disaster and often segregated in more risky neighborhoods and areas (Van Zandt et al. 2012). Thus, the poor suffer disproportionately more casualties and damage (Cutter et al. 2000).

Additionally, in the United States racial and ethnic minorities are more vulnerable to disasters because they are socially and economically marginalized and thus more likely to live in poverty (Cutter et al. 2000; Flanagan et al. 2011). Cutter et al. (2000: 20) explain that racial segregation places additional harm on minorities in that "real estate discrimination may confine minorities to certain hazard-prone areas or hinder minorities in obtaining policies with more reliable insurance companies." Furthermore, racial and ethnic minorities are not usually represented in pre- and post-disaster community planning and recovery activities because they have less economic and political capital (Van Zandt et al. 2012).

In addition, adequate language skills, education, and communications resources are necessary to access emergency information and act upon instructions to avoid harm, as well as to apply for and negotiate public financial assistance after a disaster (Flanagan et al. 2011; Van Zandt et al. 2012). In particular, language barriers for immigrant communities can greatly increase vulnerability to a disaster as communications are limited and information usually comes from networks of friends and family (Flanagan et al. 2011). Immigrants also face additional discrimination and often have feelings of mistrust or fear of government and public officials (Van Zandt et al. 2017).

Characteristic	Proxy Variable	Effect on Social Vulnerability
Economic standing	% Poverty Per capita Income	Increases High decreases; low increases
Education	% Less than high school	Increases
Social Dependence	% Social Security recipients	Increases
Employment	% Unemployed	Increases
Race and Ethnicity	% Non-White	Increases
Language	% Non-English speakers	Increases
Gender	% Female Headed Households	Increases
Family Structure	% Single Parents	Increases
Age	% Over 65 % Under 18	Increases Increases
Special Needs Populations	% Disability % Group quarters	Increases Increases
Transportation	% Households Without a Vehicle	Increases
Housing Tenure	% Renters % Homeowners	Increases Decreases
Housing Type/Quality	% Mobile Homes % Housing units built 20+ years ago	Increases Increases

Table 1: Identified Community Characteristics Contributing to Social Vulnerability (Cutter et al., 2003; Cutter et al., 2009; Ekstrom, 2015; Nutters, 2012; Peacock et al., 2010; Peacock et al., 2011; Van Zandt et al., 2012)

Gender also affects social vulnerability. Disasters have a greater impact on women, especially single mothers, because they are more likely to live in poverty and have added responsibilities as caregivers, which makes preparation, evacuation, and recovery more difficult (Cutter et al. 2009). Cutter et al. (2009: 21) explain:

> "For example, women are more likely than men are to hold low-status jobs in the service industry, which often disappear after a disaster strikes (Morrow 2008). Women are also more vulnerable to disaster because of their roles as mothers and

> caregivers: when disaster is about to strike, their ability to seek safety becomes restricted by their responsibilities to the very young and the very old, both of whom require help and supervision."

Accordingly, children and the elderly are also at a disadvantage because they rely on additional support to protect themselves or cope with hazards, and if that support is lacking or they are on their own, they suffer disproportionately.

Similarly, populations with special needs, like people who are homeless or living with physical or mental disabilities, are more susceptible to harm from disasters. These populations are less able to adequately respond to disasters and require additional assistance for hazard preparation or recovery. In hazard scenarios, caretakers who usually look after these populations may be less able to do so (Flanagan et al. 2011). Group-quarters, like for instance nursing homes and mental hospitals, in particular should be a target for emergency response due to the high proportion of special needs populations (Cutter et al. 2009).

Measuring and Mapping Social Vulnerability

As research has identified the various factors that influence the ability of an individual or group to prepare for, respond to, or recover from a disaster, calculating and spatializing social vulnerability have gained significance in the fields of hazard risk assessment and resilience planning in recent years (Cutter et al. 2009; Van Zandt et al. 2012). However, while some characteristics of social vulnerability can be easily calculated (Table 1), other concepts are difficult to quantify. For example, such factors like life lines and social networks, trust in government, and institutional capacity for disaster preparation and response require proxy variables to account for these concepts in social vulnerability calculations. Additionally, data may not be available for all factors and at all scales, which poses an additional limitation on what is calculated, where and to what degree.

Despite not fully explaining all aspects and causes of social vulnerability, such quantitative measures do help to identify concentrations of vulnerable populations and highlight areas to pay special attention to during times of emergency to reduce losses and enhance disaster response and recovery. However, there is no one way to measure social vulnerability. Many various methods exist for calculating social vulnerability indices, which can differ in scale, variables used, and cumulation approaches, and thus produce different results.

Susan Cutter and her colleagues are among the few research groups to utilize a variety of methods in mapping social vulnerability. In their 2000 article entitled *Revealing the Vulnerability of People and Places: A Case Study of Georgetown County, South Carolina*, Cutter et al. looked at both the physical and social vulnerability of a specific place, i.e. Georgetown County. They integrated the two data sets (physical vulnerability and social vulnerability) to identify and spatialize critically vulnerable zones in the area (Cutter et al. 2000). Their method for quantifying social vulnerability used eight indicators at the census block level, accounting for population and houses at risk, differential access to resources or susceptibility to hazards, wealth or poverty, and level of physical or structural vulnerability (Cutter et al. 2000). These variables were then standardized by calculating the ratio of each variable in each block. To create an index of social vulnerability, these standardized ratio values were summed for each block to produce a "broad overview of the spatial distribution of social vulnerability within the county" (Cutter et al. 2000: 727). These scores were then combined with the denotations for physical vulnerability and spatialized the overall vulnerability for Georgetown County using Geographic Information System (GIS) mapping technology.

Then three years later, Cutter et al. (2003) developed the Social Vulnerability Index (SoVI), which used a set of eighty-five indicators for over 3,000 counties in the United

States. These variables were then reduced to eleven statistically independent factors using Principle Component Analysis (PCA), which accounted for about three-quarters of the variance at the county level across the U.S. (Cutter et al. 2003). The factors were added together to calculate a summary score—the SoVI score (Cutter et al. 2003). This approach was quite comprehensive and showed social vulnerability as a stand-alone indicator of hazard risk.

In 2011, researchers at the U.S. Centers for Disease Control (CDC) created a straightforward approach for measuring social vulnerability that was more geared toward community-based planning and disaster management at the local scale. The Social Vulnerability Index for Disaster Management (SVI) used fifteen indicators organized into four categories: 1) socioeconomic status (poverty, unemployment, income, and education); 2) household composition (age, disability, and single parent households); 3) minority status (minority and language); and 4) housing and transportation (multi-unit structures, mobile homes, crowding, group quarters, and no vehicle) (Flanagan et al. 2011). (See Figure 1.) These indicators used American Community Survey (ACS) data at the census tract level and were each ranked from highest to lowest across all census tracts, save for those that had zero population. Additionally, per capita income was ranked from highest to lowest because higher values decreased social vulnerability and lower values increased it. A percentile rank was then calculated for each individual variable for each census tract. Census tracts in the 90th percentile or above received a "flag" for each variable for which that was the case (Flanagan et al. 2011). Flag counts were then summed to provide a composite SVI score to indicate high levels of social vulnerability within a community and across census tracts. Tracts with the most flags denoted areas that scored high on many indicators of social vulnerability, signifying a hotspot concentration of social vulnerability to be used by local planners and emergency managers to target policies and resources.

However, any non-zero score on the SVI flag count measure ought to also be considered by planners and emergency managers as it points to an aspect of difficulty in responding to or recovering from a disaster for a community.

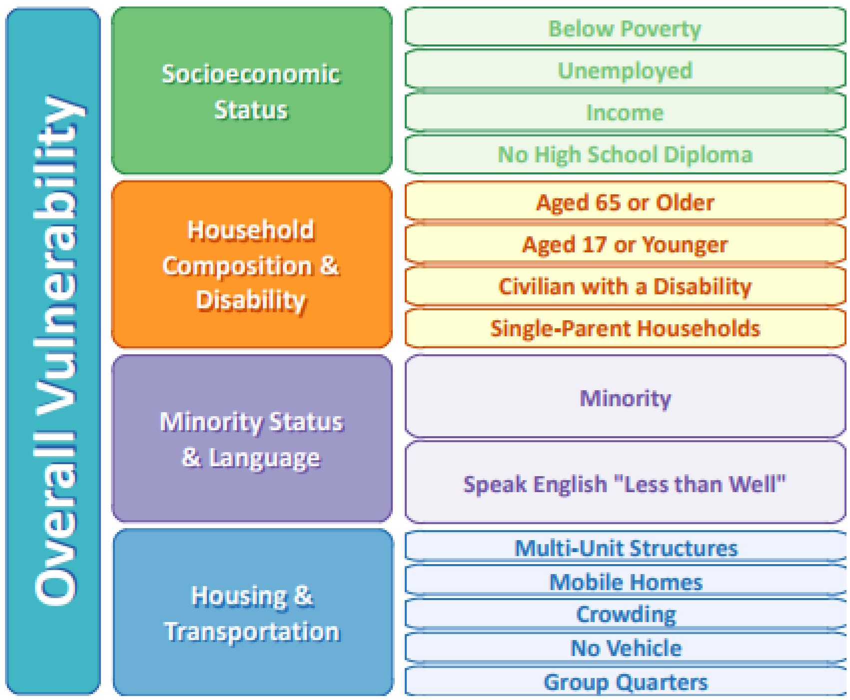

Figure 1: SVI Variables (CDC, 2017)

These pivotal studies show some of the many variations in the development of social vulnerability metrics throughout the years, which range in number and type of variables used, aggregation technique, and scale. There is no one way to assess social vulnerability and there are strengths and weaknesses of all approaches. For instance, national-scale analyses surrender local detail and distinction for comparisons across the country, and conversely local-level indices capture the specific details necessary for local emergency intervention at the expense of application in other regions. Regardless of what variables and what aggregation technique is used, there is no threshold or specific score to easily determine which communities are or are not socially vulnerable. Social vulnerability indices and maps show the relative indicators of a community's population to anticipate, respond, and recover from a natural disaster or hazard, and how that inherently changes from place to place to depict the relative saturation of social vulnerability. This information can be used by planners, emergency managers, political representatives, and even the general public to support decisions made about disaster mitigation, response, and recovery.

Chapter 3: Houston: *The Regional Context*

Houston is the largest city in Texas, the fourth largest city in the United States, and the largest city not to possess comprehensive zoning or land use regulations. The area has been characterized by rapid growth since its inception and considered a place of wealth and opportunity as the nation's energy capital, home to many oil and gas companies, as well as the space industry, and top medical research facilities, engineering firms, and universities. As such, Houston attracts many new residents every year—some years even gaining one new resident every 4.2 minutes—causing new developments and suburbs to spring up virtually overnight.[1] Additionally, as the majority of Houston area residents live in car-oriented suburban and exurban communities, the metropolitan area has expanded, now covering nine counties—Austin, Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller. (See Figure 2.) The Houston MSA spans more than eight thousand square miles—an area larger than the state of Connecticut—and contains over six million residents.

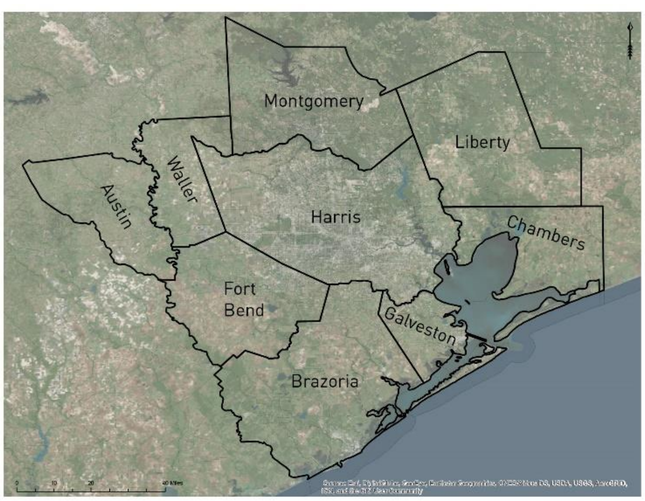

Figure 2: The Nine-County MSA

[1]The nine-county Houston metro area added 125,005 residents between July 1, 2015 and July 1, 2016, according to estimates by the U.S. Census Bureau, which equates to approximately one new resident every 4.2 minutes.

THE ECOLOGY OF HOUSTON AND THE SURROUNDING REGION

The region where Houston now lies was once a pristine, wooded, bay-studded area spilt by three major rivers, the Brazos, the San Jacinto, and the Trinity, and bordered by the Gulf of Mexico to the east. Characterized by a warm, wet climate, Live Oak savannahs, lush tallgrass prairies, humid swamps, and salt grass marshes surrounding the bays and estuaries, the Houston area sits between the Western Gulf Coast Plain and the South Central Plains ecoregions (Texas Parks and Wildlife, n.d.). (See Figure 3.)

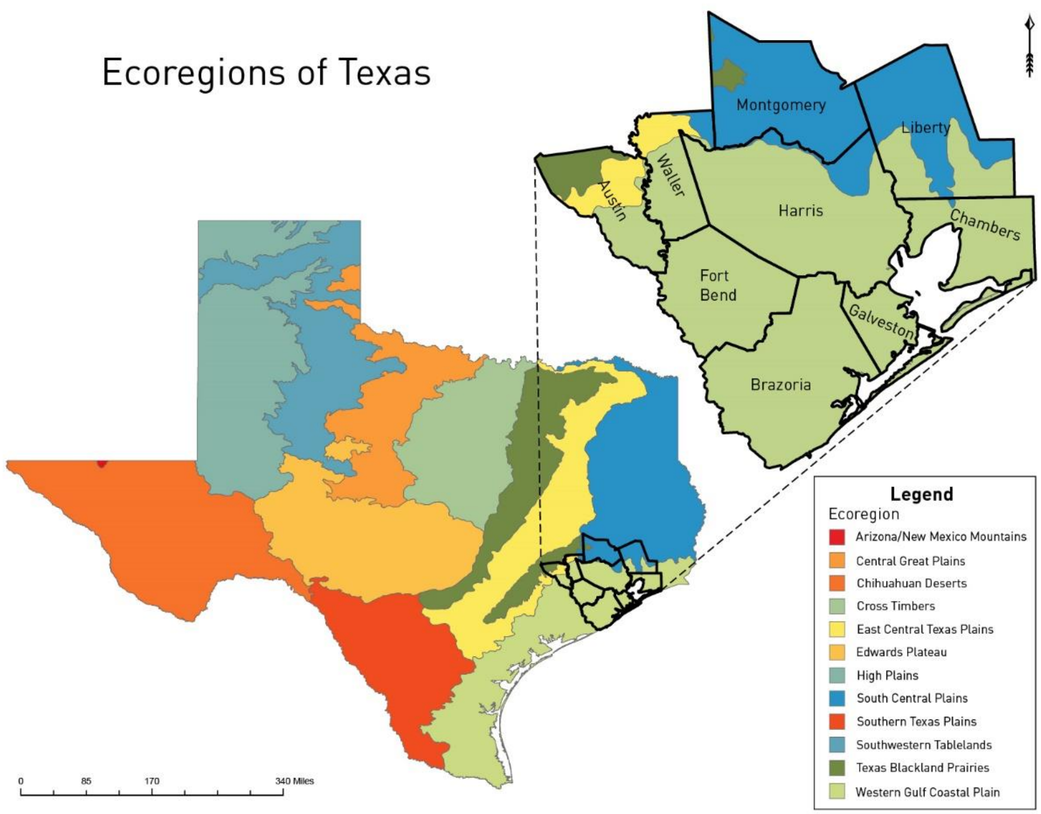

Figure 3: Greater Houston Area Ecoregions (Texas Parks and Wildlife)

The region receives an average rainfall of 40-60 inches per year and depends on a network of bayous—slow-moving streams that run into the bays of the Gulf—to gradually drain the water from the area (Texas Parks and Wildlife, n.d.). Over four hundred bayous, creeks, and streams run through the site, resulting in many smaller freshwater streams and wetlands. (See Figure 4.) Additionally, the complex clay and sandy loam soils that support the native grasslands and prairies also have moderate to high drainage capabilities to help absorb the large amounts of rain the area receives every year.

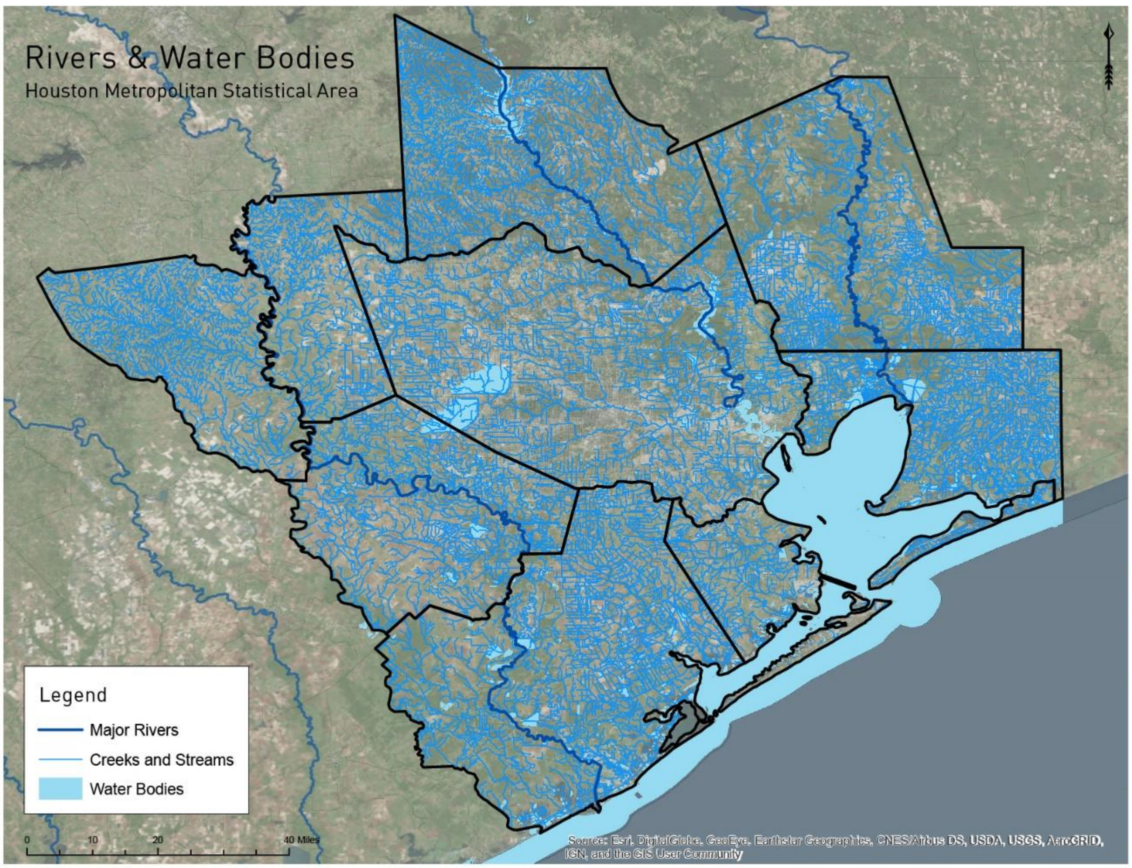

Figure 4: Greater Houston Rivers and Water Bodies (National Hydrography Dataset)

BRIEF HISTORY OF THE BAYOU CITY

The earliest inhabitants of the region were nomadic or seminomadic tribes, traveling through the area in search of the best hunting and fishing (Writer' Program, 1942). By the mid-1500s, Spain had claimed Texas as their own, but the area that is now called Houston was left mostly untouched, save for a few Spanish explorers and missionaries here and there (Johnston, 1991). After the Louisiana Purchase in 1803, many American adventurers began to look across the boundary of the Louisiana Territory to the Spanish land called Texas. In 1820, Moses Austin traveled from New England down to San Antonio de Bexar in Texas to ask the Spanish governor for permission to settle three hundred Anglo-American families in the territory (Johnston, 1991). Although Spain was generally averse to the idea of foreign settlers on its land, the Spanish governor consented and Austin was granted the contract a year later (Writers' Program, 1942). Fifteen years later, "Austin's Old Three Hundred" were among the some of the revolutionaries in the Battle of San Jacinto, where Texas won its independence from Mexico (Johnston, 1991).

The city of Houston was founded soon after in 1836 by brothers Augustus and John Allen, who bought 6,642 acres of land surrounding Buffalo Bayou (Powell, 1995). The brothers drew up a plan of the new town (see Figure 5), advertised its attractions in European and American newspapers, and persuaded the newly formed Republic of Texas to designate Houston as its first capital (Johnston, 1991). The Allen Brothers marketed Houston as a port city, close to the Gulf of Mexico with many navigable bayous for boats to come through. They also praised the area for its supply of natural resources, especially timber, and wholeheartedly guaranteed that Houston would become "the great interior commercial emporium of Texas" (Writers' Program, 1942: 38).

Although Houston was up against more established cities like Matagorda and Washington-on-the-Brazos, Congress was swayed by the Allens' argument and named Houston the national capital of the Republic of Texas in 1837 (Johnston, 1991). It was in this year that the first steamboat passed through Houston's waters, thus beginning Houston's reputation as "a port of entry" and, subsequently, the City's rapid and continuous growth trajectory (Writers' Program, 1942). However, shortly after Houston's inception as a shining city of opportunity, the new town flooded entirely (HCFCD, 2005). New residents remarked on how slowly the area drained after heavy rains and urged City officials to move the water out of the city faster. Thus, downhill-flowing channels were constructed, which got deeper and wider over time (HCFCD, 2005). However, the channels were not engineered to withstand extreme rainfall events, and so Harris County continued to flood occasionally. The area endured sixteen major floods from 1836 to 1936, some of which were so intense that downtown Houston suffered forty feet of downpour that turned the streets into white water rapids (HCFCD, 2005).

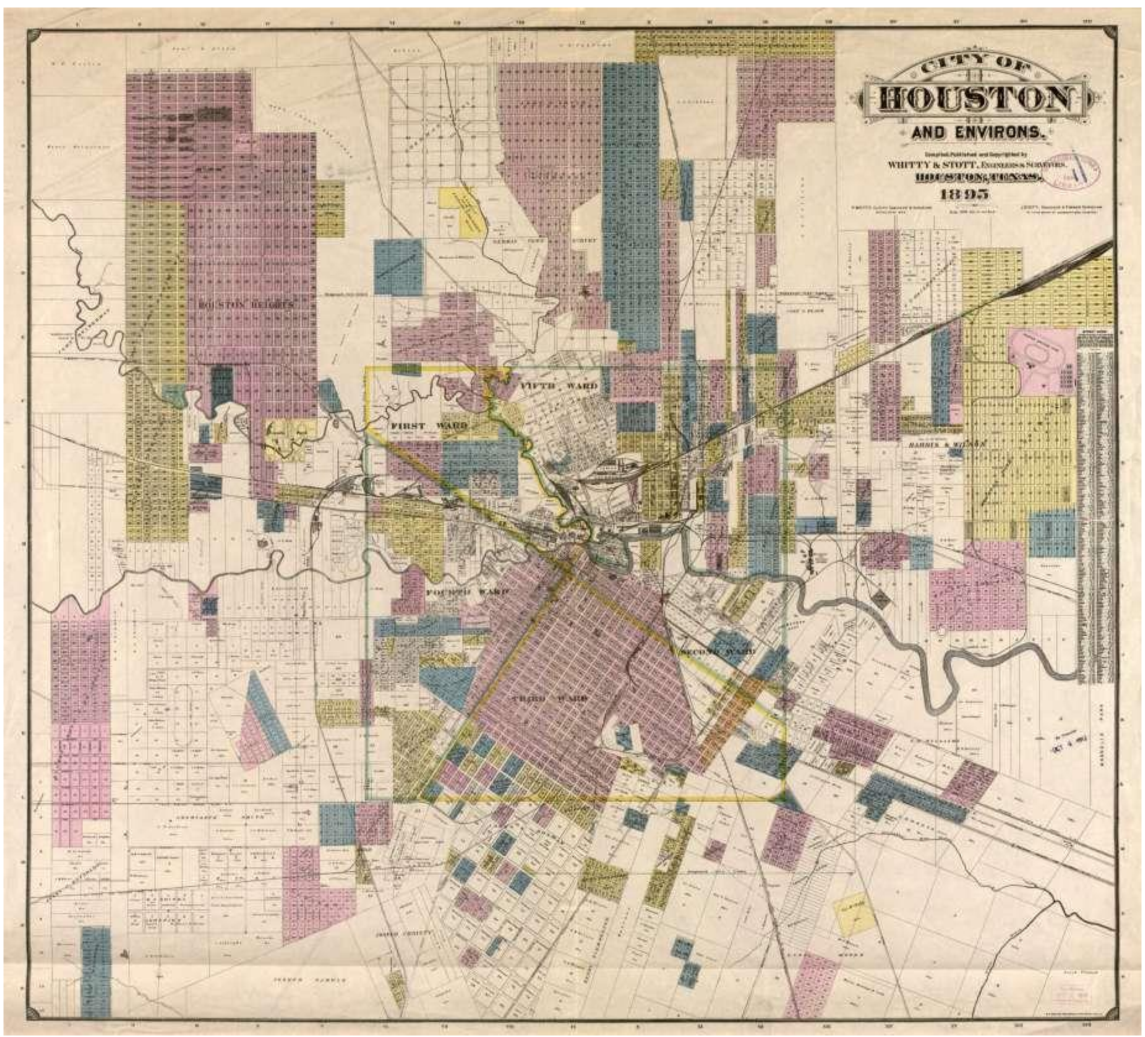

Figure 5: 1895 Map of the City of Houston (Whitty & Shott - E.P. Noll &, and Co.)

After two especially damaging floods in 1929 and 1935, which cost the city dearly, the Texas Legislature created the Harris County Flood Control District in 1937 to help appease the flooding in the area. Additionally, in 1938 Congress approved the construction of the Addicks and Barker reservoirs, which would be built by the Army Corps of Engineers to hold water back from inundating the bayous (Arcement, 2017). Although Houston continued to flood occasionally, the city still maintained to flourish. Industry and shipping came to the area, followed by extremely lucrative oils fields, and finally the technology necessary for operative space exploration and innovative medicine and infrastructure.

HOUSTON IN THE 21ST CENTURY

With few natural boundaries to growth, Houston's prairies and wooded trails were soon replaced with a sprawling web of streets and highways. By 2015, the Houston metropolis had grown to be 8,412 square miles in size with a population of 6.3 million people, according to estimates from the American Community Survey (ACS) of the U.S. Census. Today, much of the native grasslands and prairies have been lost, first to agriculture and then to urbanization. Additionally, the vast majority of this growth was and is currently unregulated, as Houston does not possess any formal zoning or land use restrictions.

According to a 2010 report from Texas A&M, between 1992 to 2010 the Greater Houston Metropolitan Area lost at least 5.5 percent of its natural freshwater wetlands (Jacob et al. 2010). The report qualifies that "although a 5 percent loss in 20 years is unsustainable by any accounting, some areas experienced loss at rates that are catastrophic. For example, Harris County lost almost 30 percent of its freshwater wetlands, including most prominently the iconic prairie pothole-pimple mound complexes" (Jacob et al.

2010:5). Furthermore, the study found that while the majority of wetlands were lost to development in the fast-growing Harris, Montgomery, Brazoria, and Fort Bend counties, the acreage of wetlands lost in Harris County was more than double that of the other counties in the area combined (Jacob et al. 2010).

The great deal of development that accompanied Houston's rapid growth in turn means more impervious surfaces like roads, parking lots, and sidewalks, along with concrete, brick, and stone building materials that cover over the native soils and prevent the natural absorption of water. Figure 6 below shows the levels of imperviousness in the Greater Houston area with high concentrations in Harris County.

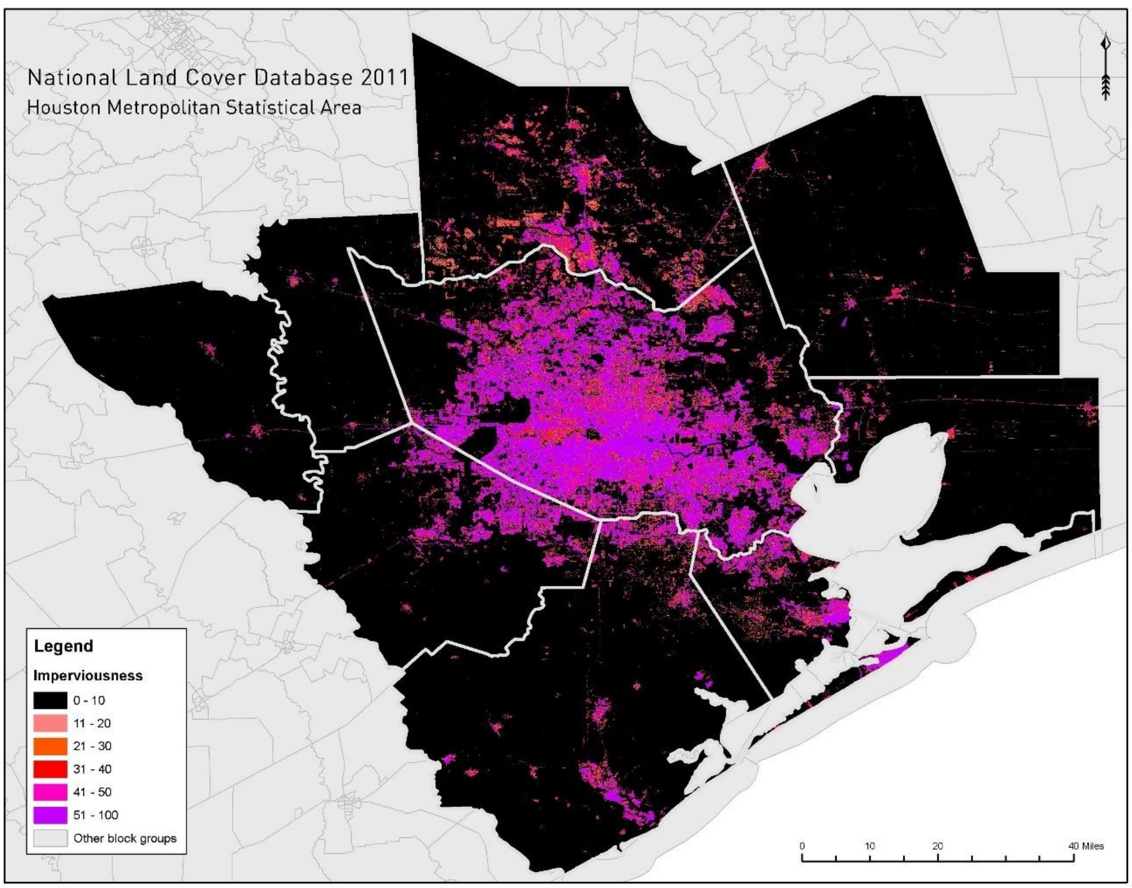

Figure 6: Levels of Imperviousness in the Greater Houston Area (NLCD, 2011).

The more impervious surfaces, the more runoff and fast flowing water after heavy rainfall events. To account for this, municipal officials have engineered several stormwater systems, like drainage channels, storm sewers, ditches, and detention ponds—otherwise known as 'gray stormwater infrastructure'—to capture the water and quickly direct it away from local areas. However, not all these systems are coordinated or up to par with one another, as many places in the unincorporated counties or recently annexed areas contain detached and aging rural infrastructure (Rosales, 2017). Additionally, the area around the Houston MSA is a hodgepodge of various municipalities and counties, all with different systems and rules and virtually no coordination for dealing with the flooding that affects the entire region. What's more, researchers at the Texas Low Income Housing Information Service claim that inadequate stormwater systems are more often found in lower-income neighborhoods of color, while the wealthier White neighborhoods typically contain high-functioning, underground storm drainage systems (Rosales, 2017). Although neither system was built to handle catastrophic flood events, those more rural open ditch systems are especially susceptible to flooding and more likely to cause damage to the residents around them (Rosales, 2017).

Demographics

As mentioned before, growth in the region has been rapid. From 2000-2015, the Greater Houston area's population increased 35 percent, which is nearly triple the national population growth rate of 12 percent for the same years. Additionally, the Houston area is exceedingly diverse with a majority minority population composed of 36 percent identifying as Hispanic, 17 percent Black, and 7 percent Asian, according to 2015 ACS data. Furthermore, while Houston is an infamously sprawling city, density does exist in the inner-city, as well as in the urban core of the eastern portion of Galveston Island. Like most cities, housing in these areas is aging and of lower quality, and it is also home to more communities of color and lower income households, i.e. more socially vulnerable populations. (See Figures 7 and 8.)

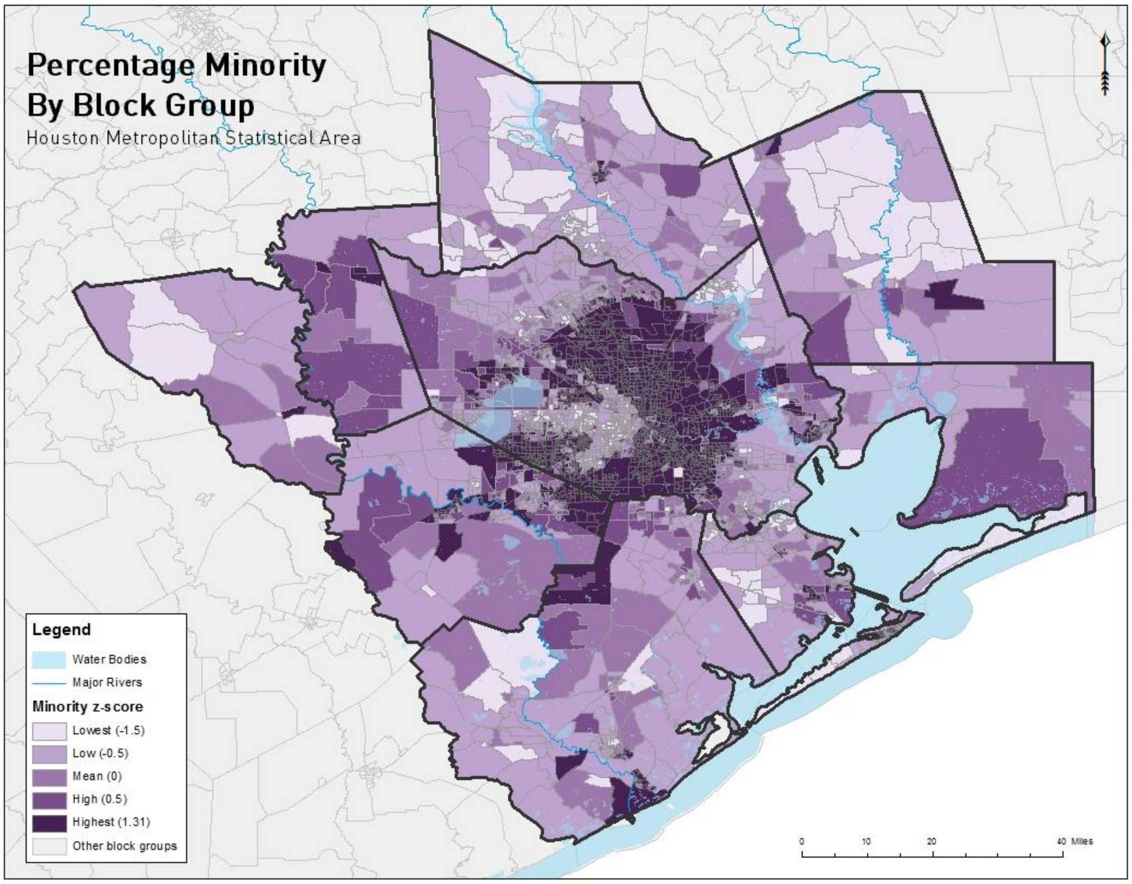

Figure 7: Percent Minority by Block Group (ACS 2015).

As Figure 7 illustrates, block groups that contain a higher proportion of racial minorities are clustered together in the eastern portion of the Houston inner city. Additionally, seeing from Figure 8, many neighborhoods in Harris County are starkly segregated by race, bounded by the highways and major roads which isolate each community from another. Moreover, as racial and ethnic minorities are more likely to live in poverty, this racial segregation also acts as a concentration of poverty and barrier to opportunity for many Houston residents.

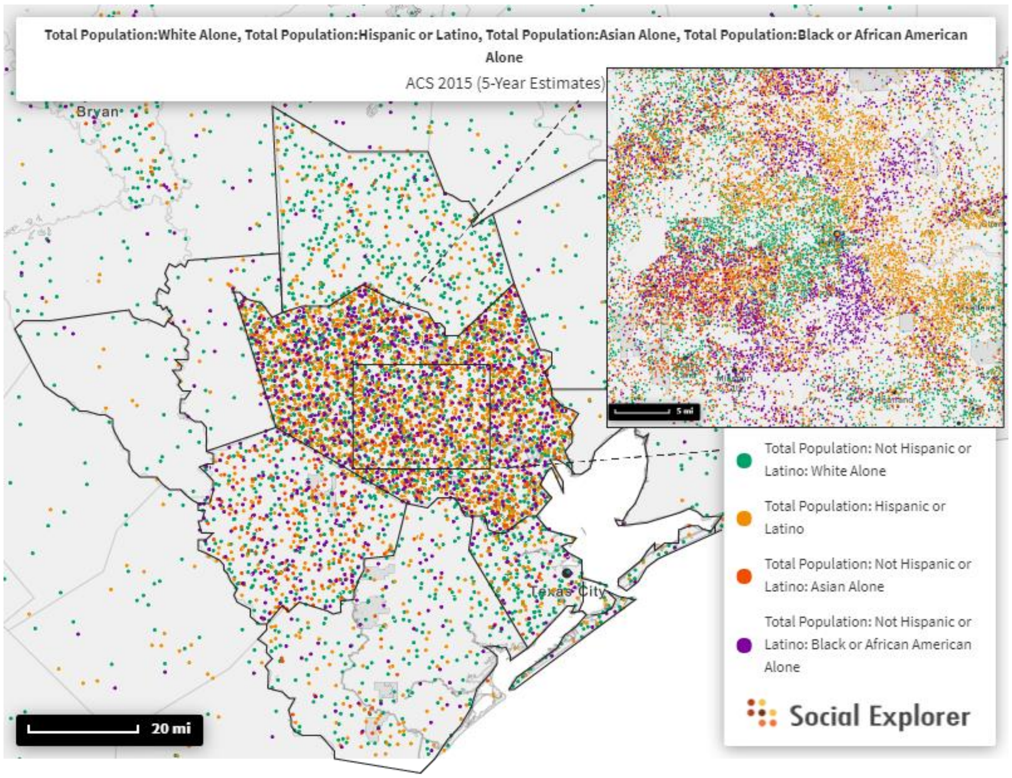

Figure 8: Population by Race/Ethnicity (Social Explorer, ACS 2015).

The Houston MSA has a median family income (MFI) of $59,649 and a 7% unemployment rate, which is better than the national average of $53,889 MFI and 8% unemployment. However, the gap between the rich and the poor is very large in Houston. In an analysis of ACS data, Houston ranked in the top ten U.S. cities for its high level of income inequality (Berube, 2018). Additionally, the study found that the measure of inequality—the ratio of incomes in the 95th percentile to the 20th percentile—increased in Houston from 2014 to 2016 (Berube, 2018).

Only 10 percent of the housing in the Greater Houston area is vacant, with the other 90 percent broken down to 61 percent owner-occupied and 39 percent renter-occupied. The Houston MSA also has some of the lowest housing costs in the county when compared to other large cities. (See Table 2.) In 2015, the median price of a single-family house was $149,300 and the median gross monthly rent was $923. However, Houston's housing affordability mostly depends on a lack of building code enforcement and cheaply-made houses, which are more vulnerable to damages from disasters. Additionally, most housing that is affordable to the lowest incomes is often found in the lowest opportunity areas, characterized by concentrated poverty and racial segregation.

Metropolitan Statistical Area (MSA)	**Median Housing Values**	**Median Gross Rent**
Houston, Texas	$149,300	$923
Dallas-Fort Worth, Texas	$156,500	$938
Atlanta, Georgia	$168,100	$977
Miami, Florida	$197,900	$1,149
Chicago, Illinois	$224,600	$998
New York, New York	$437,700	$1,280
Los Angeles, California	$470,300	$1,297
Washington D.C.	$475,800	$1,327

Table 2: Comparison of Housing Costs (ACS 2015).

Moreover, despite its comparative affordability, the Houston area still lacks sufficient affordable housing. A report from Harvard University (2017) found that 36 percent of owners and 55 percent of renters cannot afford the median price for a home. Additionally, according to an analysis of the Houston housing market from 1990-2010, there is a shortage of rental housing in the less than $600 range for low-income households making fewer than $25,000 a year, which is less than 50 percent of the median family income (Castles, 2017). This points to the assumption that many extremely low-income households are additionally cost-burdened by rent and home payments for housing that is out of their price range or living in sub-quality housing due to the increased demand and limited supply.

Planning for the Inevitable

Houston is a city built on a lowland coastal plain, covered with slow-flowing wetlands, and home to diverse groups of people with varying levels of ability and resources. Houston's rapid growth and aggressive development combined with its historic predisposition to flood and its prevailing "fairly laissez faire" approach to urban and regional planning, plus, on top of it all, climate change increasing the frequency and intensity of natural disasters, suggest that the next catastrophic flood is not far off for the region (Peacock, 2010).

Public officials now have information about what areas are more likely to flood. However, over 2 million people were already living in the region when the first comprehensive floodplain maps were created in the mid-1980s, and many families were already living in areas deemed a flood risk (Morris, 2017). The U.S. Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP) was created to protect and insure those living in the floodplains, but what it also did was encourage more floodplain development. Morris (2017) reports that "since 2010, at least 7,000 residential buildings have been constructed in Harris County on properties that sit mostly on land the federal government has designated as a 100-year floodplain." The NFIP provides data on 100-year and 500-year floodplains, which spatialize the areas that have a 1 percent and 0.2

percent chance respectively of flooding in any given year. Also referred to as flood insurance rate maps (FIRMs), these floodplain maps provide information to communities to determine their flood risk and requires the purchase of flood risk insurance by residents living within the 100-year floodplains. A quarter of the Greater Houston area is in the 100-year floodplain, and a third of the area is covered by both the 100- and 500-year floodplains. (See Figure 9 on the next page.) As such, over half of the area's population is living in areas that intersect the 100-year floodplain and nearly 80 percent is living in either the 100- or 500-year floodplain areas. (See Table 3.) Additionally, it is important to note that these floodplain maps need to be continuously updated due to climate change and Houston's rapid development, which can alter the risk of flooding for the area.

	100-Year	**100- & 500-Year**	**Not in a floodplain**
Total Population	57% (3,642,308)	78% (4,971,870)	22% (1,432,678)
Area (square miles)	9,459	9,827	867
Population Density (people per square mile)	385	506	1,653

Table 3: Population by Flood Hazard Zone for the Houston MSA (ACS 2015).

Subsequently, in the past three years, Houston has seen three 500-year flood events, with the Memorial Day floods in 2015, the Tax Day floods in 2016, and Hurricane Harvey in 2017, causing massive harm and damage to many people who were not prepared for this kind of disaster. This points to either a miscalculation of these types of flooding events in Houston or an unprecedented increase in flooding due to rapid urban growth and land use change, as well as climate change. Additionally, Houston's other development patterns, such as concentrated poverty and segregation, can cause critical impact when these disasters strike. As discussed in the previous chapter, disaster events more adversely affect those of the lowest socioeconomic status and they are less likely or able to recover, which exacerbates inequality.

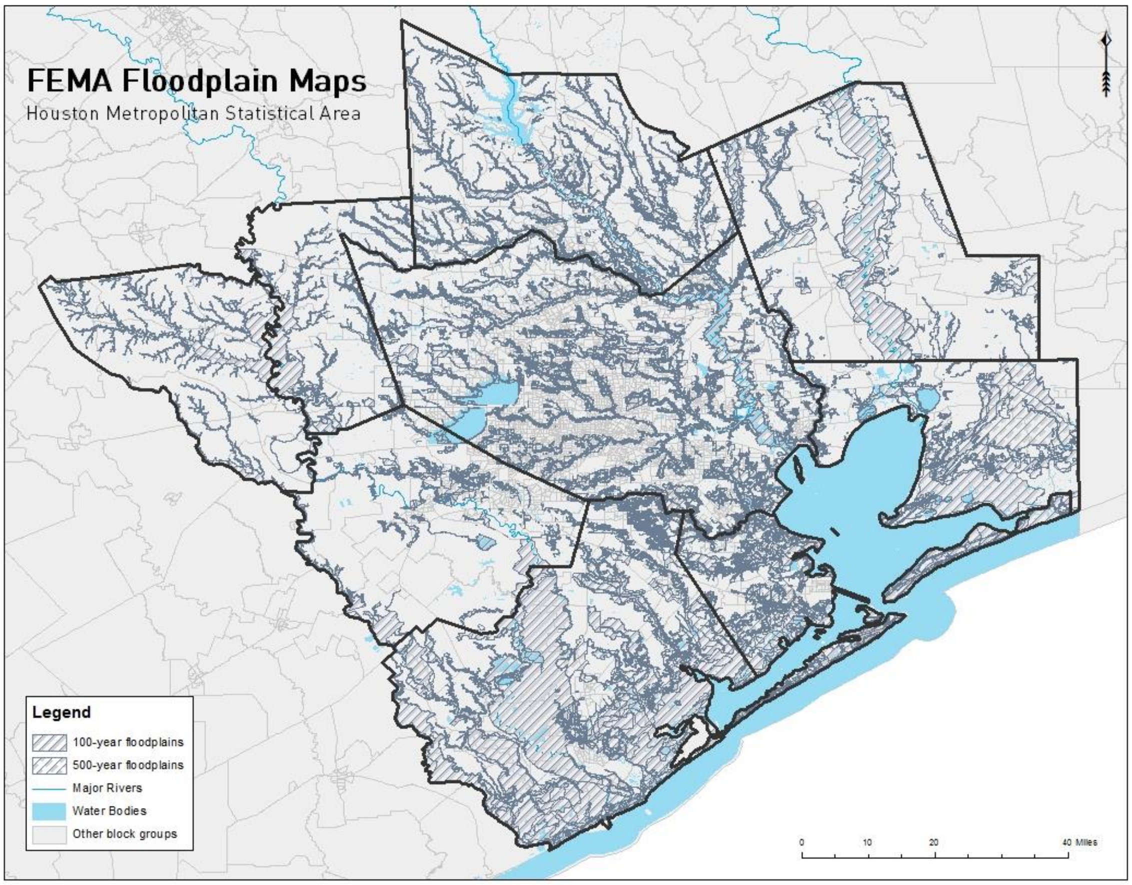

Figure 9: Greater Houston 100-Year and 500-Year Floodplains (TNRIS).[2]

[2] The FIRMs were downloaded from the National Flood Hazard Layer (NFHL) from the Texas Natural Resources Information Sheet (TNRIS) website. The NFHL contains data from 2015 and coverage is limited to final data for mapped counties. Brazoria and Galveston counties were not included in the dataset as the floodplain data for these counties is preliminary and not final. Preliminary FIRM databases for Brazoria and Galveston counties from 2017 and 2012 respectively were downloaded from FEMA's Flood Map Service Center. It is important to note that as new data on floodplains becomes available these areas could change.

Flooding is Houston's most prolific natural hazard. As the HCFCD (2005) reports, "more flood insurance funds have been paid here than in any other NFIP-participating community." As flooding becomes more frequent and less predictable, existing inequities are magnified and community resilience is thus further diminished. It is important that local resiliency planning and disaster recovery efforts more efficiently prioritize emergency management efforts, address inequities, and provide more equitable and resilient future plans for the region as a whole. Comprehensive regional planning efforts would bring a more proactive approach to hazard mitigation, which would bring better anticipation, efficiency, and ultimately resiliency for the area as a whole.

Chapter 4: Social Vulnerability in the Houston-Galveston Area

The first step toward resilience planning for the Greater Houston region is to identify target areas of highest risk and susceptibility to hazards. The method for investigating vulnerability to hazards in the Houston-Galveston area involves the construction of an index to measure social vulnerability as discussed in *Chapter 1*, mapping the index to identify vulnerable populations, and referencing and analyzing areas that are deemed a flood risk by FEMA.

IDENTIFYING SOCIALLY VULNERABLE POPULATIONS

The next task is to identify indicators for social vulnerability. The Social Vulnerability Index (SVI) developed by the CDC offers a clear and comprehensible framework for measuring social vulnerability. The index breaks down social vulnerability into four domains: socioeconomic status, household composition, minority status, and housing and transportation. Organized into these domains are fifteen demographic variables that were chosen based on a review of the literature to determine the relative vulnerability of each location (Flanagan et al., 2011).

To provide more accuracy in targeting socially vulnerable populations, this study uses census block groups as opposed to census tracts, which tend to be quite large and encompass multiple communities and neighborhoods. Census block groups, on the other hand, are smaller and can capture more refined and homogenous community data. Additionally, when constructing the index, five supplementary variables are added to the standing fifteen used by the CDC to capture additional and important dimensions of social vulnerability as suggested by other researchers. The reasoning and citations for the additional variables that are incorporated can be found in Table 4. These variables are then added and organized into the CDC's SVI framework as illustrated by Table 5.

Vulnerability Factor	Reasoning	Suggested by
Percent Households receiving Social Security	Captures retired or disabled workers, or dependents of deceased workers, who may lack resources to respond or recover from a disaster or additionally may have greater difficulties in evacuation or recovery.	Cutter et al. (2003), Cutter et al. (2009), Ekstrom (2015), Nutters (2012)
Percent of Population without Health Insurance	Accounts for the additional lack of economic capital and ability to recover from a disaster for those that do not possess health insurance.	Ekstrom (2015), Nutters (2012), Peacock et al. (2010),
Percent Female Headed Households	Accounts for the additional lack of economic capital and resources available to female head of households, who may also bear special burdens for child or elder caregiving that limit options for employment and increase difficulty in times of disaster.	Cutter et al. (2000), Cutter et al. (2009), Ekstrom (2015), Nutters (2012)
Percent Renters	Captures those that occupy more vulnerable housing as well as those that could be potentially displaced by higher rents or lower/slower recovery levels for rental housing after disaster events.	Ekstrom (2015), Nutters (2012), Peacock et al. (2011), Van Zandt et al. (2012)
Percent Housing Units Built 25+ Years Ago	Accounts for the additional vulnerability of lower quality housing that is less resistant to wind and flooding damage.	Peacock et al. (2011), Van Zandt et al. (2012)

Table 4: Demographic Variables Added to the SVI.

The Census data needed for this analysis is provided by the American Community Survey (ACS). The ACS replaced the long form of the Decennial Census in 2010 and is now the source of detailed information relating to population, housing, transportation, and other socioeconomic characteristics for all areas and across several geographic levels in the U.S. This study uses the 5-year estimates of the ACS for the 2011-2015 dataset found at the Census Bureau's FactFinder website. A detailed table showing Census variables and description of calculations can be found in the Appendix.

Domain	Variable
Socioeconomic Status	Percent individuals below poverty
	Percent unemployed
	Per capita income in 2015
	Percent persons without a high school diploma
	Percent households receiving Social Security*
	Percent population without health insurance*
Household Composition & Disability	Percent persons aged 65 or older
	Percent persons aged 17 or younger
	Percent individuals with a disability
	Percent single parent with children under 18
	Percent female headed households*
Minority Status & Language	Percent minority
	Percent households that speak English as a second language with limited English
Housing & Transportation	Percent multiunit structures
	Percent mobile homes
	Percent units that are considered crowded
	Percent households with no vehicle available
	Percent individuals in group quarters
	Percent renters*
	Percent housing units > 25 years*
*added SVI variable	

Table 5: Variables that Comprise Social Vulnerability (based on the CDC's SVI).

Constructing the Social Vulnerability Index (SVI)

To construct the index, the percentage of each indicator per block group is calculated, (ex. the number of individuals living below poverty in that block group divided by the total number of individuals living below poverty in the entire Houston MSA). Then, the mean and standard deviation for each indicator are calculated for the entire area, and from there, the z-scores are calculated for each block group to determine a percentile rank for each indicator for each block group. Census block groups with population values of zero are omitted and missing values are replaced by substituting the variable's mean value for each block group.

Each indicator was ranked from highest to lowest across all census block groups in the study area except per capita income, which was ranked from lowest to highest because, unlike the other indicators, a lower value in this category signified higher vulnerability. Those with the highest levels of vulnerability were given a “flag,” in accordance with the method established by the CDC (Flanagan et al., 2011). However, the CDC’s method “flags” indicators with percentile ranks of 90 or higher per census tract for the entire U.S., but for this study’s purposes the 85th or higher percentile rank for each block group is used given the smaller study area.

Each of these indicators explain different dimensions of social vulnerability, but frequently these characteristics present in combination, (ex. both individuals living in poverty and single parent households), which points to a multidimensional increase in overall vulnerability. As such, those areas that score high on one individual indicator are considered vulnerable, but those that score high on multiple indicators are even more vulnerable. Subsequently, the total flag counts are indexed and assigned to each block group as a final category, constituting the total value of the SVI.

Visualizing the SVI

In order to visualize the index in ArcMap, Census geography data was obtained and joined with the SVI measures.[3] Each block group’s SVI flag count value could then be displayed spatially on a map. (See Figure 10.)

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[3] 2015 Census block group shapefiles, referred to as TIGER®/Line shapefiles, were downloaded from the U.S. Census website.

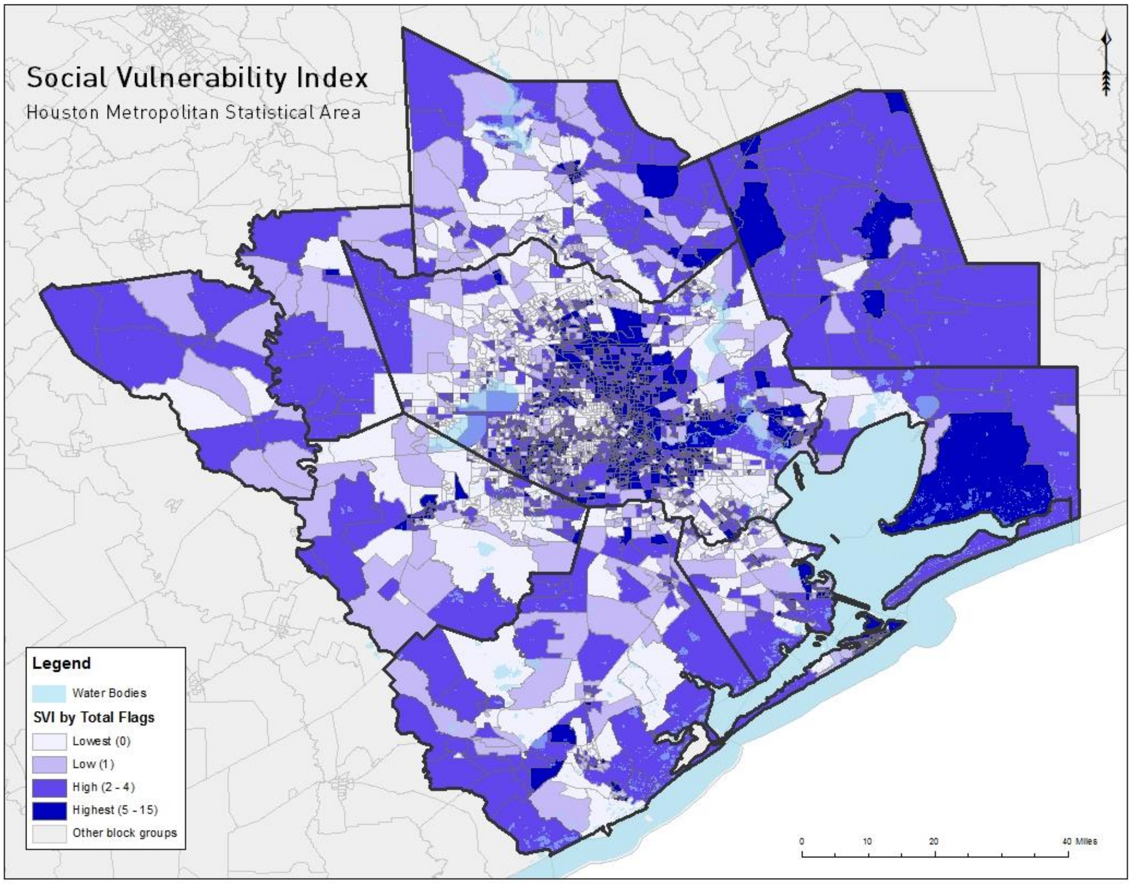

Figure 10: Social Vulnerability Index for the Houston-Galveston Area (ACS 2015).

The mean number of flags per block group is 2.76. The maximum SVI score is 15 flags (out of a possible 20) and is attributed to the block group located in the Westwood neighborhood of Southwest Houston, near Beltway 8 and I-69, which is home to 2,014 residents. This block group was flagged for all indicators except the following five variables: (1) households receiving social security; (2) persons aged 65 or older; (3) individuals living with a disability; (4) mobile homes; and (5) individuals living in group quarters.

The majority of block groups (76 percent) had at least 1 flag, with the highest proportion of socially vulnerable (1+ flags) block groups located in Harris County.

Additionally, these block groups are home to 68 percent of the total population. Nearly a quarter of the block groups in the Houston MSA are considered to belong to the highest level of social vulnerability (5+ flags), and again, the highest proportion of these block groups are located in Harris County. See Table 6 for a detailed breakdown of SVI categories and population metrics.

Houston MSA						
Social Vulnerability		Number of Block Groups	Population	Percent of Total Population	Area (sq mi)	Pop Density (People/sq mi)
Lowest	0 flags	735	2,006,809	31.6%	1,739	1,154
Low	1 flag	530	1,320,745	20.8%	1,830	722
High	2-4 flags	1,063	1,835,817	28.9%	3,946	465
Highest	5-15 flags	693	1,183,282	18.6%	897	1,319
TOTAL		**3,021**	**6,346,653**	**100%**	**8,412**	

Table 6: Level of Social Vulnerability by the Numbers (ACS 2015).

SVI Cluster Analysis

The literature on social vulnerability posits that social vulnerability is not randomly distributed in space but concentrated in spatial patterns. To demonstrate that this is the case in the Houston region this report uses the Getis-Ord Gi* tool in ArcGIS to identify statistically significant clusters or “hot spots” of social vulnerability. Figure 10 illustrates the hot spot analysis. The blue areas or “cold spots” are areas that have low SVI block groups clustered around other low SVI block groups and the red areas or “hot spots” are areas that have high SVI block groups clustered around other high SVI block groups; the white areas are not statistically significant enough from a random distribution to qualify as a hot or cold spot.

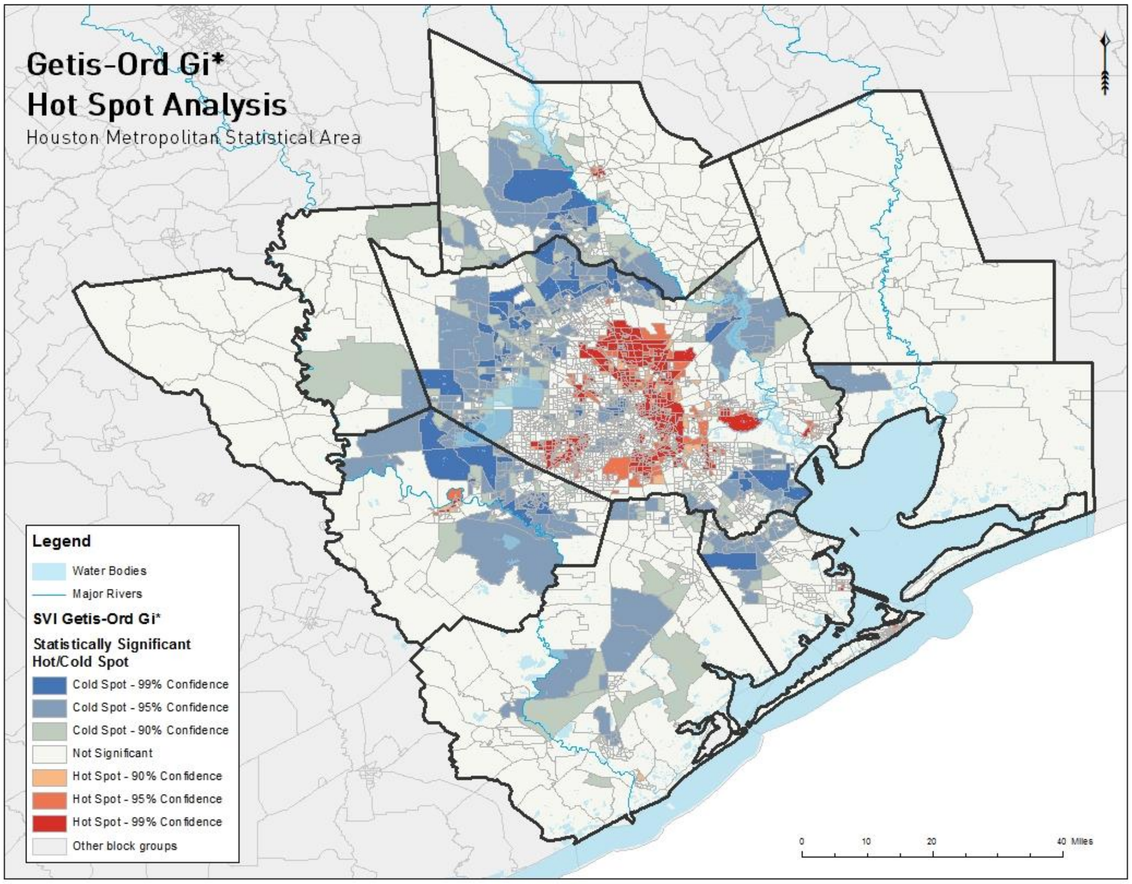

Figure 11: SVI Hot Spot Analysis for the Houston MSA.

As Figure 11 shows, social vulnerability in the Houston area is not randomly distributed, but distinctly clustered—those with the lowest social vulnerability residing in the outer band around the city of Houston and those with the highest social vulnerability concentrated in inner city, mostly in eastern crescent of Houston. These hot and cold spots also mirror the racial segregation of the Houston region with the greater proportion of non-Hispanic White population living in the suburban outer region and the greater proportion of racial and ethnic minority population living in the inner city. Such concentration of social vulnerability and racial segregation have severe consequences when disasters strike, as these areas experience extreme difficulty in bouncing back and run the risk of becoming blighted neighborhoods of economic and social despair. Such a downward spiral also threatens the vitality and resilience of the entire region.

Weighting the SVI by Population Density

Additionally, in order to aid emergency managers in more efficiently and effectively allocating resources and emergency assistance, a weighted measure can be used to determine what areas are home to the highest proportion of vulnerable populations. In this way, support and assistance can be administrated to the most people in need, although it may not be those with the highest need. As Berke et al. (2015:293-4) write, "the unweighted approach identifies the locations of populations with the greatest vulnerability regardless of counts. In contrast, the weighted approach identifies where a higher proportion of the population is vulnerable, but not necessarily those with the greatest vulnerability."

Consistent with the methods used by Berke et al (2015) and Van Zandt et al. (2012) the SVI flag count score is multiplied by the measure of population density in each block group to account for block groups with high SVI flag counts, but very few people living in the block groups themselves. Thus, population density acts as a measure with which to weight the SVI. Accordingly, a block group that has a high SVI flag count score and a lot of people living there scores higher than one with a similar SVI flag count score but is home to fewer people. See Figure 12 on the next page for the spatial distribution of the weighted SVI.

As Figure 11 illustrates, the weighted SVI tends to favor smaller block groups, with the highest vulnerability block groups clustering in Harris County. The block group with the highest score on the weighted SVI is home to Napoleon Square, an apartment community located in Southwest Houston. While this block group only has nine flags, it has a population of over two thousand residing in a 0.03 square mile area. Alternatively, the block group that contains the Westwood neighborhood, which scored highest on the unweighted SVI, now has the third highest score on the weighted SVI due to its slightly lower population density compared to other block groups.

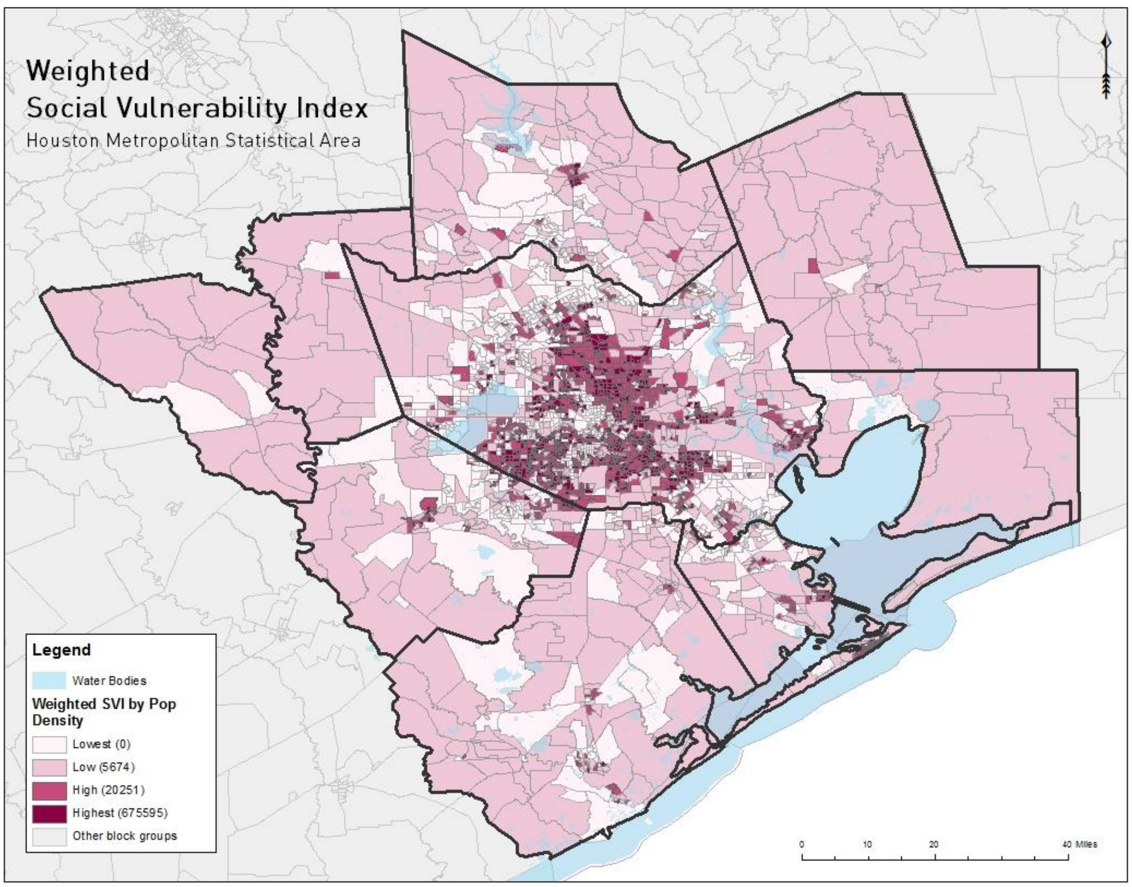

Figure 12: Weighted SVI for the Houston MSA (ACS 2015).

The weighted SVI tends to favor smaller block groups, with the highest vulnerability block groups clustering in Harris County. The block group with the highest score on the weighted SVI is home to Napoleon Square, an apartment community located in Southwest Houston. While this block group only has nine flags, it has a population of over two thousand residing in a 0.03 square mile area. Alternatively, the block group that contains the Westwood neighborhood, which scored highest on the unweighted SVI, now has the third highest score on the weighted SVI due to its slightly lower population density compared to other block groups.

VULNERABILITY IN THE FLOODPLAINS

Because the 100- and 500-year floodplains intersect the vast majority (72 percent) of block groups in the Greater Houston region, they encompass the greatest variability in SVI measures. However, Table 7 shows that both of the average measures of the Raw SVI and Weighted SVI increase as you get further from the 100-year floodplain, meaning that more vulnerable populations are living further from high risk areas, which points to an encouraging distribution of vulnerable populations in the Houston-Galveston area.

	100-Year	**100- & 500-Year**	**Not in a floodplain**
Mean SVI (Raw Flag Count)	2.32	2.59	3.20
Mean SVI (Weighted)	10,192.84	15,399.06	32,846.68
Number of Block Groups Intersected	1,507	2,179	842

Table 7: SVI by Floodplain Zone.

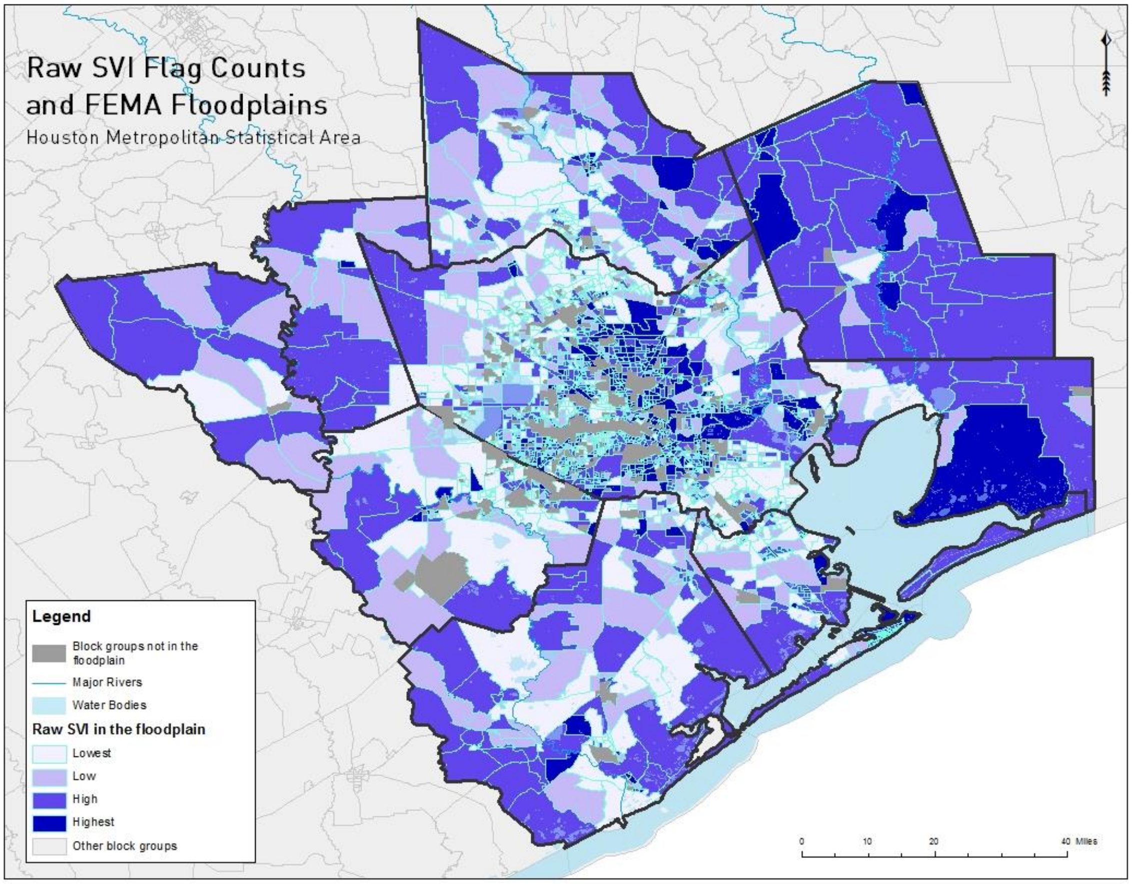

Figure 13: Raw SVI in the 100- and 500-Year Floodplains.

Block groups that do not intersect the floodplains tend to be smaller, denser, and more socially vulnerable. However, there are still many vulnerable residents living in the 100- and 500-year floodplains, as these areas contain 78 percent of the total population for the area. Of the population living in the floodplain areas, 16 percent is in the highest vulnerability category. (See Figures 13 and 14.) Additionally, with Houston's rapid growth and development and the impact of climate change, many households in areas outside of the floodplains have been affected, sometimes repeatedly, by recent flooding disasters.

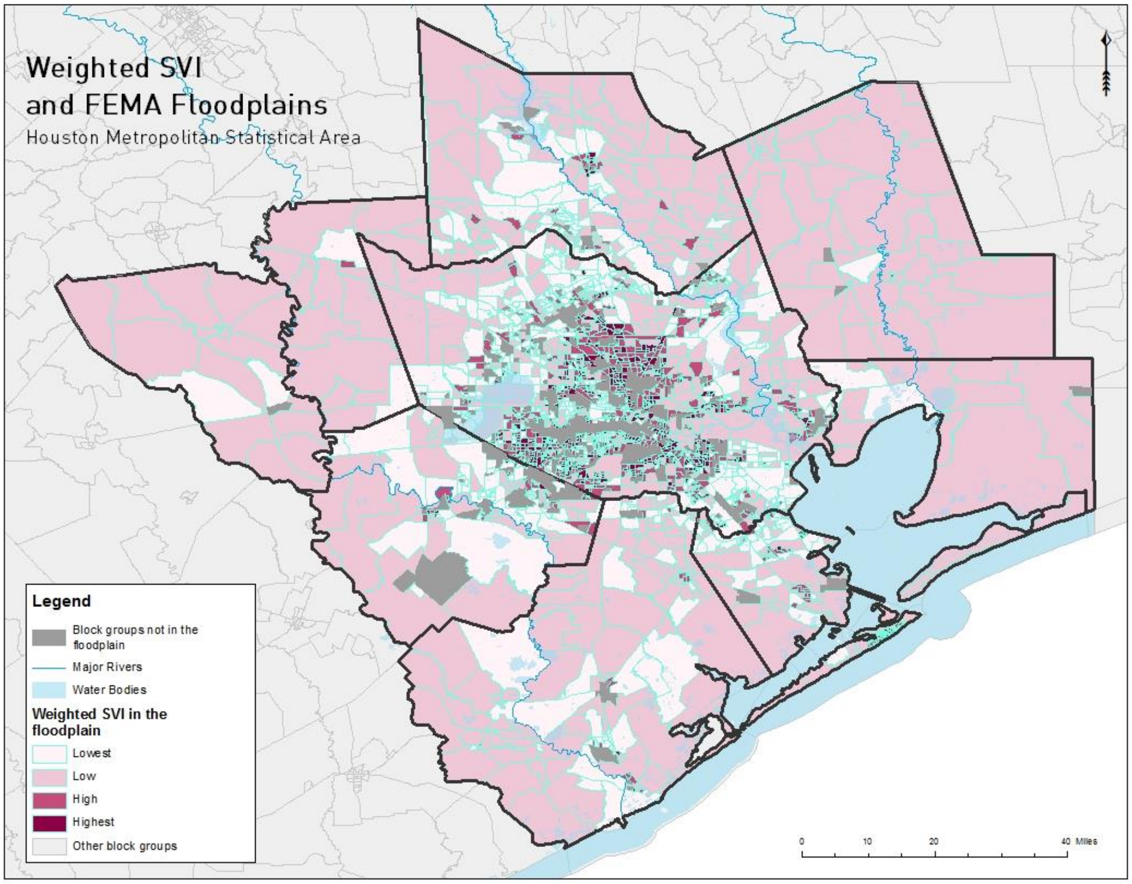

Figure 14: Weighted SVI in the 100- and 500-Year Floodplains.

Chapter 5: Hurricane Harvey

Hurricane Harvey was one of the largest and most furious storms that the nation has ever seen. Harvey made landfall in Rockport, Texas on August 25th, 2017, and for six days afterward storms raged up the Texas coast. Harvey was a category 4 hurricane with wind speeds of 130 miles per hour, but most of the damage from Harvey came from the massive amount of rainfall, which created a devastating 1,000-year flood event. Although local officials were anticipating Hurricane Harvey's arrival in Houston, its scale and impact on the region was unprecedented. With such severe rain in such a short amount of time, the flooding that resulted was unlike anything that Houston had seen before.

Harvey by the Numbers

Harvey deluged the gulf area, pouring a total of 33 trillion gallons of water—19 trillion of which was in Texas—over the course of several days (Fritz and Samenow, 2017; FEMA, 2017). By September 1st, one-third of Houston was underwater. Some Houston neighborhoods received more than 50 inches of rain, setting a new record for a single storm in the United States (Garfield et al., 2017; FEMA, 2017). Millions of people were affected, hundreds of thousands of homes were impacted by flooding, thousands of residences were destroyed or seriously damaged by over a foot of water in their homes, and more than 80 lives were lost.

As of September 22, 2017, there were nearly 800,000 households that had registered for assistance with FEMA (FEMA, 2017). More than $1.5 billion in federal funds was paid to Texas residents who were impacted by the disaster, which included assistance grants, low-interest disaster loans and flood insurance advance payments (FEMA, 2017). However, there is still a significant unmet need as many households outside of the 100-year floodplain (i.e. those not required to purchase flood insurance) were seriously affected by the storm and unprepared to deal with its consequences. Additionally, as previous chapters have pointed out, many socially vulnerable populations do not have the capability or access to apply and receive federal funding, and furthermore are hit harder by disaster events, making it more difficult to recover.

How Harvey Measures Up to Other U.S. Flooding Disasters

Prior to Harvey, Hurricane Katrina was one of the most devastating natural disasters to ever hit the U.S, from which the city of New Orleans is still trying to recover. In Houston, until Harvey hit, Hurricane Ike had been the last hurricane to impact the area and Tropical Storm Alison had been the worst storm the region had seen. Table 8 shows a comparison of the effects of these three disasters to Hurricane Harvey.

	Tropical Storm Alison	**Hurricane Katrina**	**Hurricane Ike**	**Hurricane Harvey**
Year	2001	2005	2008	2017
Number of Residents Affected	2 million	15 million	3 million	13 million
Lives Lost	41	1,800+	100+	88
Economic Impact	$5-12 billion	$100-160 billion	$30-35 billion	$150-190 billion
Rainfall	30+ inches	15+ inches	20+ inches	50+ inches

Table 8: Comparison of Disasters in the Houston Region and Beyond. (Complete, Inc., 2008; Dewan and Schwartz, 2017; Dottle et al., 2017; Garfield et al., 2017; Williams, 2017; Willingham, 2017)

As the table above points out, although the scale of damage and amount of rainfall the Houston area withstood was record breaking, the death toll was significantly less than Hurricane Katrina. Some attribute the relatively low number of deaths caused by Harvey to the number of lives saved by effective anticipation of impact by inundation maps and subsequent flood response efforts by search and rescue (Maidment, 2018).

However, much of the flooding was made worse by the region's stormwater infrastructure failings. The Houston region contains a patchwork quilt of stormwater infrastructure; most urban stormwater infrastructure is created and maintained by city staff in a widespread coordinated effort, but the stormwater infrastructure in recently annexed or suburban areas stormwater infrastructure was mostly decided upon by individual suburban developers, resulting in many areas built with isolated and inadequate drainage. As such, local officials do not have uniform control of the region's drainage, the consequence of which is an uncoordinated and inefficient network of stormwater infrastructure that was not adept to handle Harvey's waters.

Harvey Damage Assessments

One of the most apparent effects of storms is the damage they cause to property. While many hurricanes can cause damage by both their powerful winds and their storm surges, most of the damage in the Houston area from Harvey was due to the intense amount of rainfall as the rain-band around the edge of the hurricane deluged Houston for several days. For this report, two measures of damages are presented—one based on a flooding model from FEMA straight after Hurricane Harvey hit and the other from the U.S. Department of Housing and Urban Development (HUD), which used FEMA assistance application approvals and inspection data a few months after the hurricane to determine damages by Census block group.

FEMA Inundation Model

The first and largest dataset available to assess the damages in the Houston area in the aftermath of Hurricane Harvey was compiled by FEMA. FEMA focused on twelve impacted counties in Texas and used parcel data, land use codes, and modeled flood depth grids to determine potential impacts. By overlaying the rainfall and flood inundation information with the building inventory data, FEMA was able to calculate an estimate of the magnitude of damages. FEMA separated the level of damage into 4 categories: (1) affected properties were those that received two feet or less of flooding; (2) minor damaged properties were those that received between two to five feet of flooding; (3) major damaged properties were those that received between five to eight feet of flooding; and (4) destroyed properties were those that received more than eight feet of flooding. The extent of damages in the Houston region is illustrated by Figure 14 and Table 9 below.

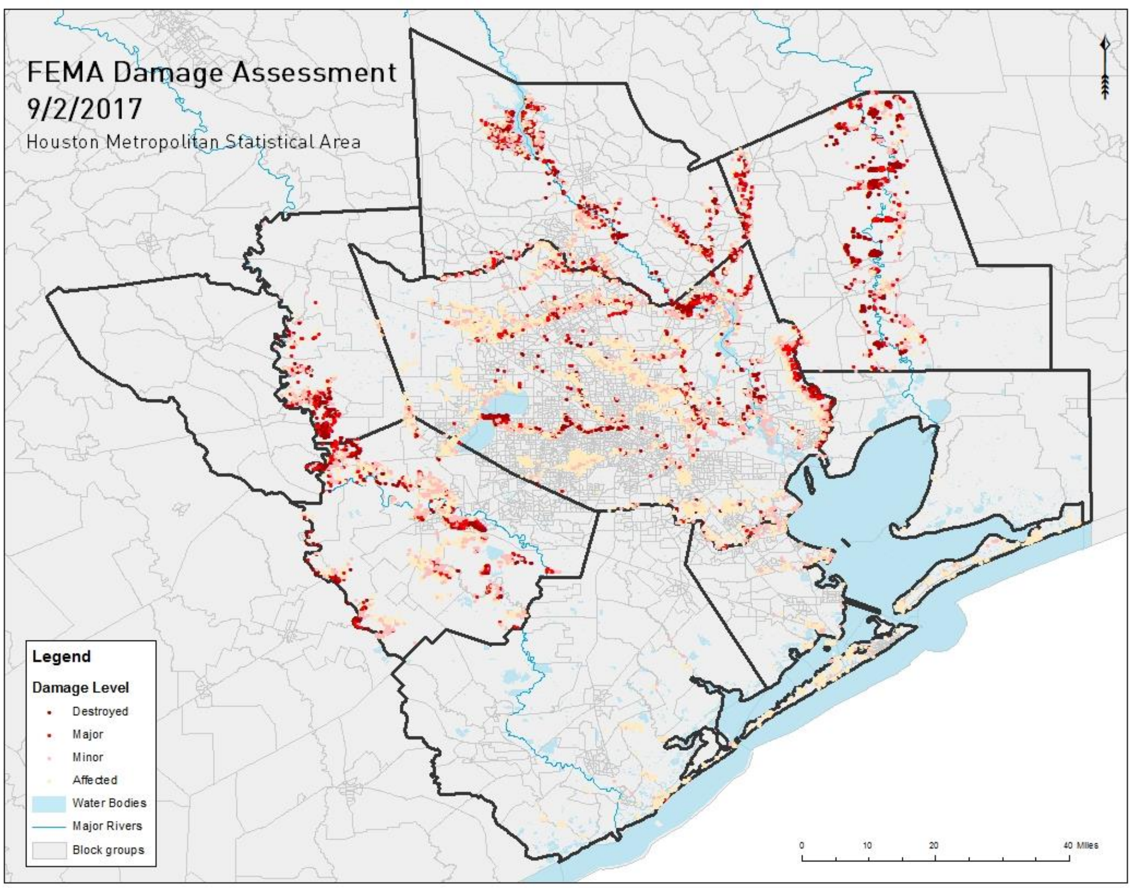

Figure 15: Houston Building Damage Estimates from Hurricane Harvey (FEMA, 2017)

Level of Damage	Affected	Minor Damage	Major Damage	Destroyed
Number of Properties	52,835	31,052	10,946	9,848

Table 9: Harvey Damage Assessment by the Numbers (FEMA, 2017).[4]

This model was first run in the midst of Hurricane Harvey on August 29, 2017 and then was run again on September 2, 2017 as the storm receded and more data became available. However, while this is the largest damage dataset obtainable, it is still preliminary and limited and is not considered a fine and complete assessment of all the damages in the region. For instance, the model could not account for structures that had been elevated and thus might have avoided or lessened the extent of damage. Additionally, FEMA's methodology did not account for flooding resulting from stormwater backups, irrigation ditch failures, flooding from dam or levee breaks, use of spillways and weirs, or resulting wind damage.

HUD Serious Damage by Block Group

On November 28, 2017, HUD compiled a dataset of "seriously damaged" owner- and renter-occupied homes per Census block group. Owner-occupied homes were considered "seriously damaged" if the structure had incurred more than $8,000 of FEMA inspected real property damage and/or one or more feet of flooding on the first floor. Similarly, renter-occupied homes were considered "seriously damaged" if the structure had incurred more than $2,000 of FEMA inspected personal property damage and/or one or more feet of flooding on the first floor. (See Figure 15.)

[4] Hurricane Harvey damage assessment data was downloaded from the FEMA data sharing site and can be found at the FEMA Cloud GIS Infrastructure Production Site. The dataset was then clipped to the 9-county Houston region.

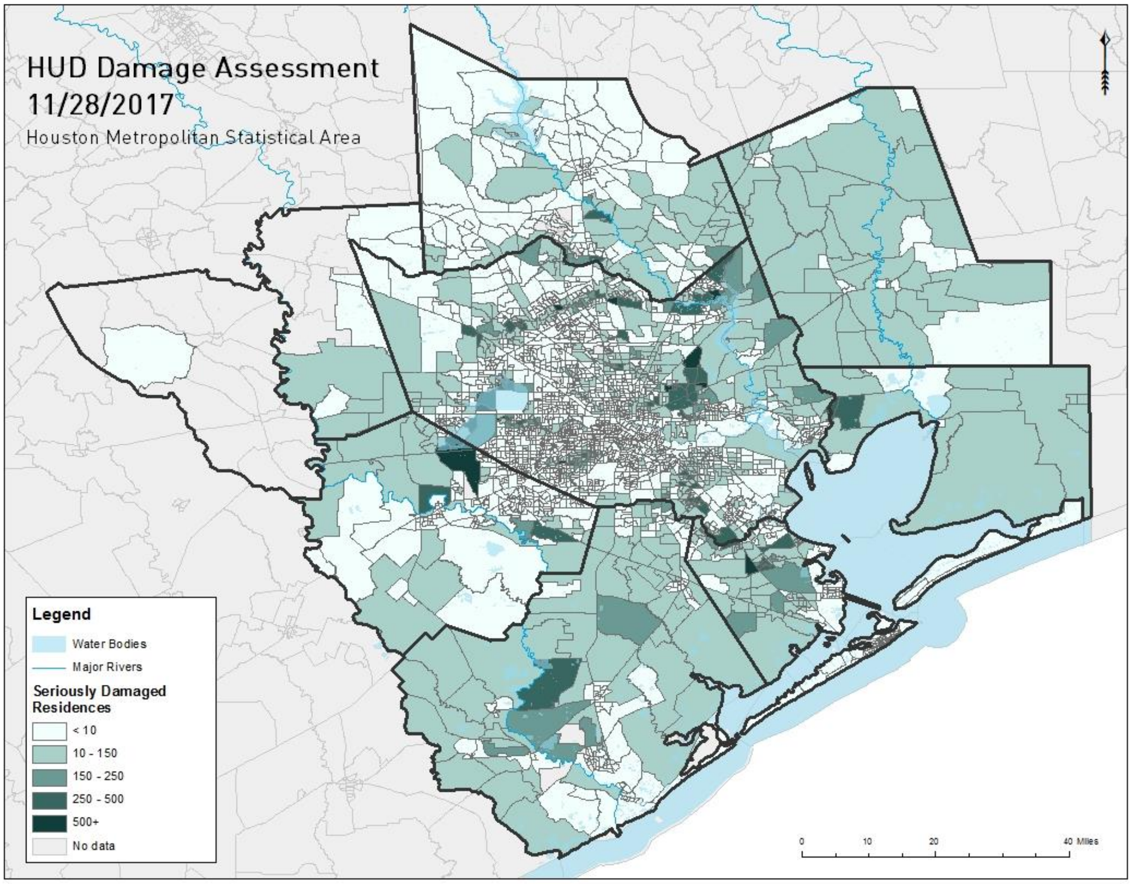

Figure 16: Houston Housing Damage by Block Group (HUD, 2017).[5]

To protect the confidentiality of those adversely affected by Hurricane Harvey, Census block groups containing ten or fewer damaged homes were listed as containing at least one seriously damaged property. As such, the number of seriously damaged properties in the Houston region came to an approximate total of 87,150 residences. However, it is important to note that not all homes were inspected; only residents that applied for assistance from FEMA and who did not already have an adequate policy were inspected. Thus, this dataset leaves out homes that were damaged, but whose owners did not have the

[5] Total Hurricane Harvey damages by block group were downloaded from the HUD open data website. Only the block groups within the 9-county Houston region are displayed.

capacity or ability to apply for assistance, and those homes that were damaged, but whose owners maintain a policy that did not warrant an inspection. Additionally, this dataset was last updated by HUD more than four months ago, which might leave out important data that has progressed since then.

Other Damage Assessments

FEMA has ownership of better and more complete data, but usually reports publicly at the zip code level. The scale of zip codes is so large that detailed analysis is nearly impossible, and it is very difficult to track the progress of the recovery on the ground. In order to adequately assess and monitor the progress of the recovery efforts, FEMA's cooperation is necessary to get data at the smallest level possible, while still protecting individual privacy, (i.e. the block group level). In this way, local and regional officials can be aware of the recovery progress and pit falls to effectively take action to ensure that everyone has an equal chance to recover and reestablish their lives.

RELATING THE SVI TO HARVEY DAMAGES

In order to relate the SVI to the two damage assessments from FEMA and HUD, all data must be consolidated by Census block group. Additionally, to easily compare the two damage assessments to each other, all minor damaged, major damaged, and destroyed properties from the FEMA inundation model are added together to determine the number of "seriously damaged" properties in the area. Figure 16 shows a comparison of HUD and FEMA calculations of seriously damaged properties by SVI category. As the chart illustrates, both HUD and FEMA damage assessments calculate the highest number of damaged properties in the High SVI areas (2-4 flags per block group), followed by the Lowest SVI (0 flags), Low SVI (1 flag), and finally the Highest SVI (5-15 flags).

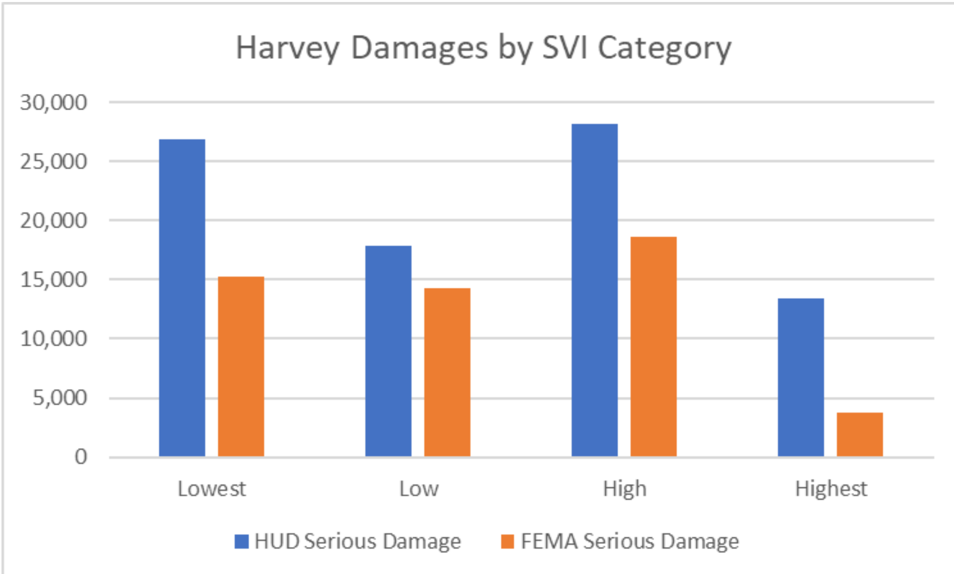

Figure 17: Comparison of HUD and FEMA Damage Calculations by SVI Category.

In order to determine if there is a correlation between social vulnerability and magnitude of damages incurred by Hurricane Harvey, a linear regression analysis is performed. Table 10 shows the relationship between the two measures of damages (dependent variables) and the social vulnerability indices and indicators (independent variables). Given the research on social vulnerability, it is surprising that the relationship between both damage calculations and social vulnerability measures generally shows that blocks with higher levels of SVI suffered lower amounts of damage. However, as mentioned before, both datasets are limited and not complete pictures of the damages after Hurricane Harvey, and this may be the cause of bias in the analysis. The data from FEMA only approximates the number of properties damaged based on an inundation model and does not account for other factors that may make individual homes or entire communities more susceptible to flooding and damage (i.e. lower quality homes, inadequate stormwater infrastructure, etc.). Additionally, the data from HUD only comes from those residents that have applied for assistance with FEMA (i.e. residents that have the capability, access, and opportunity to do so) and does not account for the total real number of properties damaged.

	FEMA Serious Damage	HUD Serious Damage
Overall SV Indices		
Raw SVI	-2.55*	-2.44*
Weighted SVI	-0.0001*	-0.0001*
Individual Indicators		
Individuals below poverty	-4.96	-7.29
Unemployed	2.44	-0.76
Per capita income	-8.37	-7.58
Persons without a high school diploma	0.19	-0.28
Households receiving Social Security	3.22	-7.94
Population without health insurance	-4.88	-2.25
Persons aged 17 or younger	8.45	14.41*
Persons aged 65 or older	17.21*	3.53
Individuals with a disability	-4.28	1.78
Single parents with children under 18	-4.88	-0.67
Female headed households	-6.55	-6.8
Minority	-4.85	-0.15
Households with limited English	1.47	-7.13
Multiunit structures	-3.81	-6.06
Mobiles homes	1.71	4.72
Units that are considered crowded	-1.63	-6.14
Households with no vehicle available	-7.12	-5.91
Individuals in group quarters	26.17*	-4.42
Renters	-4.01	-2.16
Housing units older than 25 years	-11.57	3.75

* statistically significant at $p < 0.01$

Table 10: Correlation between SV Indicators and Damage Data.

Additionally, when looking at the correlations of the individual indicators that contribute to social vulnerability there is generally not a statistically significant relationship to either damage calculation. The few exceptions are the positive correlations of flags for high proportions of persons aged 65 and older and individuals in group quarters to the FEMA damage calculation, and the positive correlation of a flag for high proportion of persons aged 17 and younger to the HUD damage calculation. These significant positive correlations suggest that block groups with the highest numbers of elderly residents, children, and group quarters suffer greater relative damage. Overall, the results from the regression analysis were not as expected given the literature on social vulnerability. However, it must again be noted that both damage calculations are limited, and this may weaken the analysis.

DISCUSSION

Hurricane Harvey unleashed the worst storm the Houston area had ever seen. Severe flooding forced thousands of people out of their homes and into shelters. Damage calculations from FEMA and HUD combined with the SVI analysis of this report estimate that the flooding from Harvey has seriously impacted many socially vulnerable households. Additionally, a majority of privileged middle class and wealthy households were seriously damaged as well, as the regression analysis pointed out. As Hurricane Harvey has affected everyone across the spectrum and throughout the region, some might call this an "equal opportunity disaster," but there is clearly a difference in who is able to fully recover and get back on their feet after a 1,000-year flooding disaster like this and the literature on social vulnerability attests that the poorest and most vulnerable suffer more when disasters strike.

Houston has a responsibility to protect its residents in recovery efforts and build back better. The scale and quality of recovery efforts must be equitably distributed to meet the needs of all residents, regardless of income, race, education, or immigration status. Many are calling for Houston to address its long-standing inequities, like concentrated poverty and segregation, in its rebuilding efforts to create a strategy that will create a stronger, more equitable and resilient city. Additionally, regional collaboration and comprehensive planning efforts would bring a more proactive approach to hazard mitigation to prepare Houston for the next flood that will most likely occur.

Harvey also has brought climate change to the forefront of planning and policy discussions. Houston cannot continue "business as usual," building and developing virtually unchecked at the expense of flood control, as climate change will likely increase Houston's propensity to flood with more frequency and intensity. It is the responsibility of local and regional officials to plan, prepare, and try to mitigate the effects.

Chapter 6: Conclusion

Recovery from Hurricane Harvey will take years for the Houston region, but this can be an opportunity for change, growing public support for resilience planning and building back better. This report provides a framework for reducing disparities through effective vulnerability mapping at the smallest scale available, (i.e. Census block groups). As natural disasters compound existing conditions of poverty and inequality, community planners, emergency managers, and other local officials must be made aware of what areas have the highest risk in order to effectively target recovery efforts and better meet the needs of the community.

However, it is important for communities to have access to complete data in order to track recovery efforts and respond effectively to inefficiencies. The data publicly available by FEMA is limited and cooperation is needed from the agency in order to successfully monitor the recovery trajectory. Better information would also improve the ability of planners to plan for resilience. FEMA and other federal agencies should consider creating databases for transparent and up-to-date information on disaster impacts, recovery efforts, and vulnerability of residents to aid local officials in their efforts to reduce hazard risks and improve community resilience.

Appendix

Domain	**Indicator**	**Data Yr**	**Source**	**Census file**	**Census file name**	**Census table variable(s)**	**Census level**	**Downloaded from**	**Description**
Socioeconomic Status	Percent individuals below poverty	2015	ACS (5-year estimates)	C17002	Ratio of Income to Poverty Level in the Past 12 Months	HD01_VD02; HD01_VD03	Block Group	FactFinder	Individuals below poverty= “under .50” +“.50 to .74” + “.75 to .99.” Percentage of persons below federally defined poverty line, a threshold that varies by the size and age composition of the household. Denominator is total population where poverty status is checked.
	Percent unemployed	2015	ACS (5-year estimates)	B23025	Employment Status for the Population 16 Years and Over	HD01_VD05	Block Group	FactFinder	Individuals in civilian labor force, but unemployed. Percentage of persons unemployed. Denominator is total population where employment status is checked.
	Per capita income in 2015	2015	ACS (5-year estimates)	B19301	Per Capita Income in the Past 12 Months (in 2015 Inflation-Adjusted Dollars)	HD01_VD01	Block Group	FactFinder	Mean income computed for every person in census block group (in inflation-adjusted dollars).
	Percent persons without a high school diploma	2015	ACS (5-year estimates)	B15003	Educational Attainment for the Population 25 Years and Over	HD01_VD02 - HD01_VD16	Block Group	FactFinder	Percentage of persons 25 years of age and older, with less than a 12th-grade education (including individuals with 12 grades but no diploma).

	Percent households receiving Social Security*	2015	ACS (5-year estimates)	B19055	Social Security Income in the Past 12 Months for Households	HD01_VD02	Block Group	FactFinder	Percentage of households receiving Social Security income.
	Percent population without health insurance*	2015	ACS (5-year estimates)	B27010	Types of Health Insurance Coverage by Age	HD01_VD17; HD01_VD33; HD01_VD50; HD01_VD66	Block Group	FactFinder	For all age groups - the total of individuals with no health insurance coverage.
Household Composition & Disability	Percent persons aged 65 or older	2015	ACS (5-year estimates)	B01001	Sex by Age	HD01_VD20 - HD01_VD25; HD01_VD44 - HD01_VD49	Block Group	FactFinder	Male individuals aged 65 or older + Female individuals aged 65 or older. Denominator is total population.
	Percent persons aged 17 or younger	2015	ACS (5-year estimates)	B01001	Sex by Age	HD01_VD03 - HD01_VD06; HD01_VD27 - HD01_VD30	Block Group	FactFinder	Male individuals aged 17 or younger + Female individuals aged 17 or younger. Denominator is total population.
	Percent individuals with a disability	2015	ACS (5-year estimates)	B22010	Receipt of Food Stamps/Snap in the Past 12 Months by Disability Status for Households	HD01_VD03; HD01_VD06	Block Group	FactFinder	Households that received Food Stamps/SNAP with 1 or more persons with a disability + Households did not receive Food Stamps/SNAP with 1 or more persons with a disability. Denominator is total population where Food Stamps/SNAP status is checked.

	Percent single parent with children under 18	2015	ACS (5-year estimates)	B11003	Family Type by Presence and Age of Own Children Under 18 Years	HD01_VD10; HD01_VD16	Block Group	FactFinder	“Other family: male householder, no wife present, with own children under 18 years” + “Other family: female householder, no husband present, with own children under 18 years.”
	Percent female headed households*	2015	ACS (5-year estimates)	B11003	Family Type by Presence and Age of Own Children Under 18 Years	HD01_VD15	Block Group	FactFinder	“Other family: female householder, no husband present."
Minority Status & Language	Percent minority	2015	ACS (5-year estimates)	B03002	Hispanic or Latino Origin by Race	HD01_VD04 - HD01_VD09; HD01_VD12	Block Group	FactFinder	Total of the following: “Black or African American alone” + “American Indian and Alaska Native alone” + “Asian alone” + “Native Hawaiian and other Pacifi c Islander alone” + “some other race alone” + “two or more races” + “Hispanic or Latino – White alone.”
	Percent households that speak English as a second language with limited English	2015	ACS (5-year estimates)	B16002	Household Language by Household Limited English Speaking Status	HD01_VD04; HD01_VD07; HD01_VD10; HD01_VD13	Block Group	FactFinder	For all languages - the total of "Limited English speaking households"
Housing & Transportation	Percent multiunit structures	2015	ACS (5-year estimates)	B25024	Units in Structure	HD01_VD07 - HD01_VD09	Block Group	FactFinder	Percentage of housing units with 10 or more units in structure.

	Percent mobile homes	2015	ACS (5-year estimates)	B25024	Units in Structure	HD01_VD10; HD01_VD11	Block Group	FactFinder	Percentage of housing units that are mobile homes.
	Percent units that are considered crowded	2015	ACS (5-year estimates)	B25014	Tenure by Occupants Per Room	HD01_VD05 - HD01_VD07; HD01_VD11 - HD01_VD13	Block Group	FactFinder	At household level, more people than rooms. Percentage of total occupied housing units (i.e., households) with more than one person per room.
	Percent households with no vehicle available	2015	ACS (5-year estimates)	B25044	Tenure by Vehicles Available	HD01_VD03; HD01_VD10	Block Group	FactFinder	Percentage of households with no vehicle available.
	Percent individuals in group quarters	2015	ACS (5-year estimates)	B09019	Household Type (Including Living Alone) By Relationship	HD01_VD38	Block Group	FactFinder	Percentage of individuals "in group quarters."
	Percent renters*	2015	ACS (5-year estimates)	B25003	Tenure	HD01_VD03	Block Group	FactFinder	Percentage of rental households.
	Percent housing units > 25 years*	2015	ACS (5-year estimates)	B25034	Year Structure Built	HD01_VD06 - HD01_VD11	Block Group	FactFinder	Total of structures built before 1989.

*non-CDC SVI variable

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